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This report presents the results of an initial assessment of potentially promising approaches for circa 1990 IAS satellite communications. A survey of satellite systems parameters was performed and the cost effectiveness of various satellite configurations was determined.

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I. INTRODUCTION

I. INTRODUCTION

1. OBJECTIVES AND PURPOSE

This report presents the results of a task under Contract DCA 100-77-C-0057 to assess the application and utilization of satellite transmission for an Integrated AUTODIN System (IAS) circa 1990. The study was conducted with two major objectives in mind. The first was to determine what the characteristics and capabilities of satellite systems will be in 1990. This includes a survey of satellite communication technology, multiple access techniques, and hardware and launch costs. The second objective was to determine if satellite communications holds promise for implementation in an "IAS only" network. This involves the determination of technical feasibility as well as cost effectiveness.

With these objectives in mind, it was the purpose of this study to provide a "first cut" towards the identification of potentially promising approaches for 1990 IAS satellite communications, eliminating those approaches which clearly were not feasible.

2. SCOPE

a. General. It should be emphasized that this report is a preliminary assessment of satellite transmission utilization for the IAS and is not intended to be an in-depth technical analysis. Many assumptions were made which, to some extent, may be optimistic. It is not the intent of this task to propose a final system design; rather, potential satellite applications that might be applicable and cost effective to the circa 1990 IAS are suggested based on cost and technical tradeoffs. For these reasons, the scope of the study was purposely restricted. The following paragraphs describe the scope of the major phases of the task.

b. Industry Survey and DCS Planning. This phase was the prime input to the determination of technical characteristics of circa 1990 satellite systems and to the determination of costs as functions of capabilities of the space and ground segments. The source and type of data obtained included:

- System planning documents and company interviews within the satellite carrier industry, e.g., COMSAT, Satellite Business Systems, NASA.

- Research programs within the commercial satellite communications equipment industry, e.g., Ford Aerospace and Communications, General Electric, Hughes.

c. Requirements Data From DCEC. In order to realistically assess satellite transmission requirements, the present and future DCS AUTODIN systems were characterized. Data was obtained from DCEC interviews, documents and data bases for both AUTODIN I and the CONUS AUTODIN II, and included:

- Switch locations
- Traffic flow between switch locations
- Minimum functional requirements
- Cost data for the current terrestrial system.

This data was used in lieu of developing a "bottom up" 1990 requirements data base. Such an effort was beyond the scope of this task, and would have required a more definitive system architecture than is presently available.

d. Terrestrial System Configuration and Cost. Since the cost of terrestrial transmission is directly related to the system architecture (which is not yet defined) cost estimates were based on current figures and industry trends in data transmission. An overall system model was developed to evaluate the cost tradeoffs involved as the coverage of the terrestrial transmission network was varied.

e. Evaluation of Satellite Broadcast in the IAS. This phase used the data developed in earlier portions of the study to reach overall conclusions. The evaluations encompassed satellite system hardware, launch and operating costs as well as the technical performance of candidate broadcast techniques. Detailed satellite system design and tradeoffs were not undertaken, as only initial feasibility determination was desired. The overall evaluation compared satellite approaches against minimum technical requirements and the estimated cost of an equivalent terrestrial system.

f. IAS and the Overall DCS. Since this study is concerned with the the applicability of broadcast satellite communications to the 1990 IAS alone, an examination of the desirability or feasibility of providing an integrated satellite communications network serving the entire DCS (voice, data, facsimile, and dedicated user services) was avoided. An integrated system approach, however, may have significant impact on user systems as well as on satellite system design and major impact areas have been identified where it was felt that significant tradeoffs might be required.

3. ASSUMPTIONS AND GUIDELINES

a. General. Many assumptions have been made in this study concerning future IAS configurations. The terrestrial transmission system is most affected by the assumptions because of cost sensitivity to distance, particularly for subscriber access lines. In comparison, the satellite system cost is not distance dependent, but rather is dependent primarily on the total number of earth stations. The basic tradeoff in the implementation of a satellite system is therefore the number (and cost) of earth stations required versus the savings achieved through the elimination of terrestrial lines. The remainder of this section describes the major assumptions made for the terrestrial and satellite networks.

b. Terrestrial Assumptions. The terrestrial transmission portion of the IAS will be extremely cost-sensitive to the overall network topology. In the absence of a well defined IAS, it was assumed for the purposes of this study that the 1990 system topology will be similar to that which exists for the current AUTODIN. There will be 15 "nodal areas" which roughly correspond to the areas served by today's ASCs. These areas will contain from one to "N" PSN nodes, the number "N" being the primary independent variable for consideration in this study. All N switching nodes were also assumed to be in place. Since the cost comparisons which were developed were designed to compare a satellite based IAS transmission system with an equivalent terrestrial system the cost of additional switching facilities was ignored. It is recognized that the use of satellites may dramatically change some switch functions (such as tandem switching and route selection) and may even affect the overall systems approach (i.e., is packet data switching still valid?), but these are questions which must be answered in an overall IAS context. Modem and cryptographic costs were similarly not considered since these depend highly on system configuration, however, the reduction of individual secure links in a satellite system can be expected to reduce these costs significantly.

Within each nodal area subscribers and traffic were assumed to be homogeneously distributed. The various nodal areas worldwide do differ in subscriber densities and average line lengths however, and by assuming that the relative distributions between nodal areas will remain the same and that each area is homogeneous, detailed traffic projections for each area are not required.

A final assumption regarding the terrestrial network structure concerns subscriber connections. All subscribers are assumed to be connected directly to a PSN backbone switch (or to an access switch colocated with a backbone switch). Without concentration or multiplexing. Inclusion of the latter would dictate detailed analysis of each subscriber area, which, as previously mentioned, was beyond the scope of this task.

While these assumptions remove much of the ambiguity in projecting terrestrial system configuration and cost, many variables still exist between now and 1990 which could significantly affect terrestrial system costs. These are discussed in greater detail in Chapter IV of this report.

c. Satellite Assumptions. For the purposes of this study was assumed that the space segment of the satellite communication system will be comprised of DSCS III assets or INTELSAT V equivalent spacecraft. These represent the satellite technologies that will be in place in 1990. Although new systems and technologies will be under development by that time, and an initial operational capability (IOC) may even be achieved, it is too early to say with any degree of certainty what the capabilities will be. Therefore, the assumptions of DSCS III and INTELSAT V space segments provide conservative estimates of 1990 system capabilities and costs.

The allocation of satellite transponder assets also affects satellite system implementation. In this study it was assumed that the IAS satellite network was given sole use of a single transponder (both power and bandwidth) in each satellite, and cost figures were developed based on this hypothesis. The implications of the sharing of transponders will be discussed in greater detail in conjunction with satellite link budget analysis in Chapter VI. Earth segment analysis used cost data extrapolated from prior studies which was assumed to represent current component and system costs.

Since the overall IAS configuration is not yet known, no accurate estimates could be made of the number and types of switching nodes which would exist in 1990. Therefore, the "alternate scenarios" approach of the original task statement (i.e., analyzing alternatives using satellite links for backbone, regional access and local access, and various combinations of these) was dropped in favor of a "parametric" approach which used the number of earth terminals as the independent variable. This allowed the analyses to be performed without detailed knowledge of the overall system architecture.

4. REPORT ORGANIZATION

The remainder of this report is divided into seven chapters. In Chapter II, the study approach and methodology is outlined. Also included are technical parameters of the AUTODIN system which will be used further in the tradeoff analyses. AUTODIN traffic needline matrices and switch capacities for 1978, 1980, and 1990 are developed in Chapter III. These projections form the basis for sizing transmission line requirements and earth terminals. Chapter IV "looks into the future" and configures and costs an all-terrestrial AUTODIN system.

In Chapter V, an overview of satellite technology is presented. Descriptions of satellite space segment characteristics as well as ground segment requirements are contained in this chapter. Based on 1990 traffic requirements, and projected terrestrial configurations, Chapter VI develops a family of curves that indicate the relative costs of satellite implementations over an all-terrestrial system. Chapter VII then presents a strawman scenario illustrating a possible IAS satellite communication network for 1990. The final chapter presents the study conclusions and recommendations.

II. APPROACH AND ANALYSIS CRITERIA

II. APPROACH AND ANALYSIS CRITERIA

1. APPROACH

a. General. The approach taken to determine the applicability of broadcast satellite communications for the 1990 IAS was basically one of extrapolation and comparison. The assumed system configurations were based on the present AUTODIN system and current planning for Phase I of AUTODIN II. Traffic requirements were based on these two sources as well as on projected growth rates through 1990.

A complete list of references and data sources used in this study is presented at the end of this report.

b. Traffic Model. Traffic requirements were developed using the approach shown in Figure 1. The baseline CONUS AUTODIN I configuration and traffic statistics were obtained and compared with the AUTODIN II, Phase I, requirements. A traffic ratio was developed from this data base and was used to project European and Pacific AUTODIN II equivalent traffic requirements. Estimated growth factors were then used to postulate a worldwide IAS traffic profile for 1990 which includes:

- Worldwide switch regions
- Traffic statistics by originating to destination switch
- Worldwide AUTODIN needline traffic capacities
- Worldwide AUTODIN traffic mix.

The traffic figures thus derived were then used to size satellite networks and to determine approximate terrestrial system capacities.

c. Performance Criteria. Any communications system must meet certain minimum performance standards. For this study, criteria which could be used in "first cut" evaluations of satellite system alternatives were felt to be of greater importance than detailed performance specifications. The overall IAS system specification served as a guide in determining these criteria.

Perhaps the most important factor in data communications via satellite is the intrinsic transmission delay (aaproximately one quarter second from earth station to earth station). This delay can create significant, if not intolerable, response time requirements for some system configurations and implementations. Therefore, performance criteria used for evaluation were heavily oriented toward delay related measures, such as:

WORLDWIDE DIN I TRAFFIC

FROM/TO	RUAD		RUWT	TOTAL ORIGI-NATED
RUAD	X	–	–	–
⋮		X		–
RUWT	–	–	X	
TOTAL TERMI-NATED	–	–	–	–

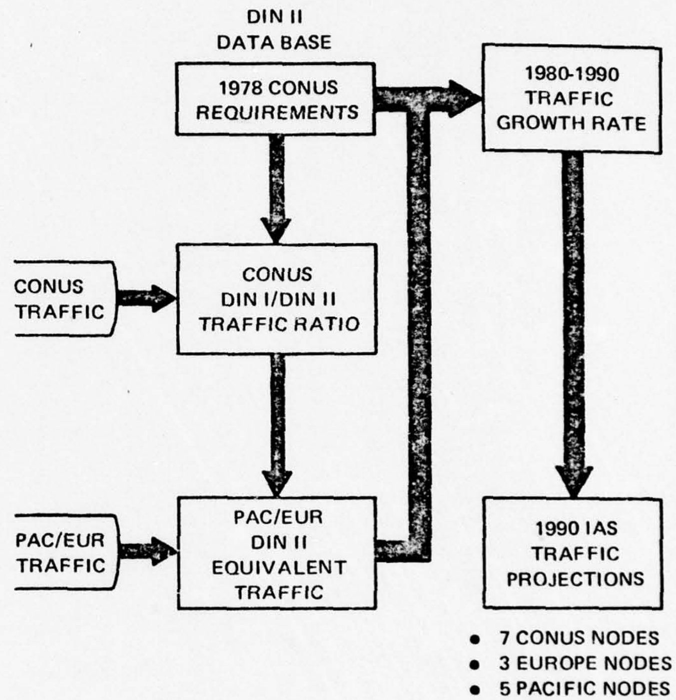


Figure 1. 1990 IAS Configuration and Traffic Estimation Approach

- Transmission delay budget
- Response time requirements for each type of traffic
- Maximum number of satellite links permissible for each type of traffic.

These are discussed more fully in the final section of this chapter.

d. Satellite Configurations. As mentioned previously, the methodology employed during this task used a parametric approach for determining the relative cost of broadcast satellite implementation. Rather than assume a given number of nodes and nodal locations, costs were determined as a function of the number of earth stations employed. To do this it was assumed that in 1990 the traffic load in the present AUTODIN switch regions would be evenly divided among a number of (smaller) nodes, each with a colocated earth terminal and serving a proportionate number of subscribers. A range of from one to forty nodes per AUTODIN switch region was felt adequate to cover all possible alternatives, ranging from a "backbone only" satellite system to one in which dedicated earth stations could serve numerous small user clusters. This approach also preserved the variations in traffic loads which currently exist in different portions of the AUTODIN (e.g., Pacific, CONUS and Europe). Figure 2 illustrates this approach.

e. Terrestrial Configuration. For the same reasons that a parametric approach was used for the satellite configurations, a similar approach was required to estimate terrestrial costs. As the number of satellite earth stations increases, the amount of terrestrial lines exhibits a corresponding decrease. The method used in this analysis was to assume a homogeneous distribution of subscribers within each area presently served by an AUTODIN switch. As this area is subdivided, the number of subscribers is also divided among the smaller areas. Similarly, access line lengths (and costs) are reduced as a result of re-homing these subscribers on a smaller switch serving the new sub-regions. This approach enables terrestrial costs to be evaluated on the same basis as satellite costs, without considering the detailed IAS architecture.

f. Cost Determination. The estimated costs for both the satellite and terrestrial portions of the 1990 IAS transmission system were determined primarily by synthesizing the network from its individual components (earth stations, satellite launches, terrestrial costs, etc.). Costs were based on current (1977) rates, and were adjusted to projected 1990 costs by applying an inflationary factor and by allowing for the influences of technology where its impact was clearly identifiable. System costs are discussed in greater detail in Chapter VI of this report.

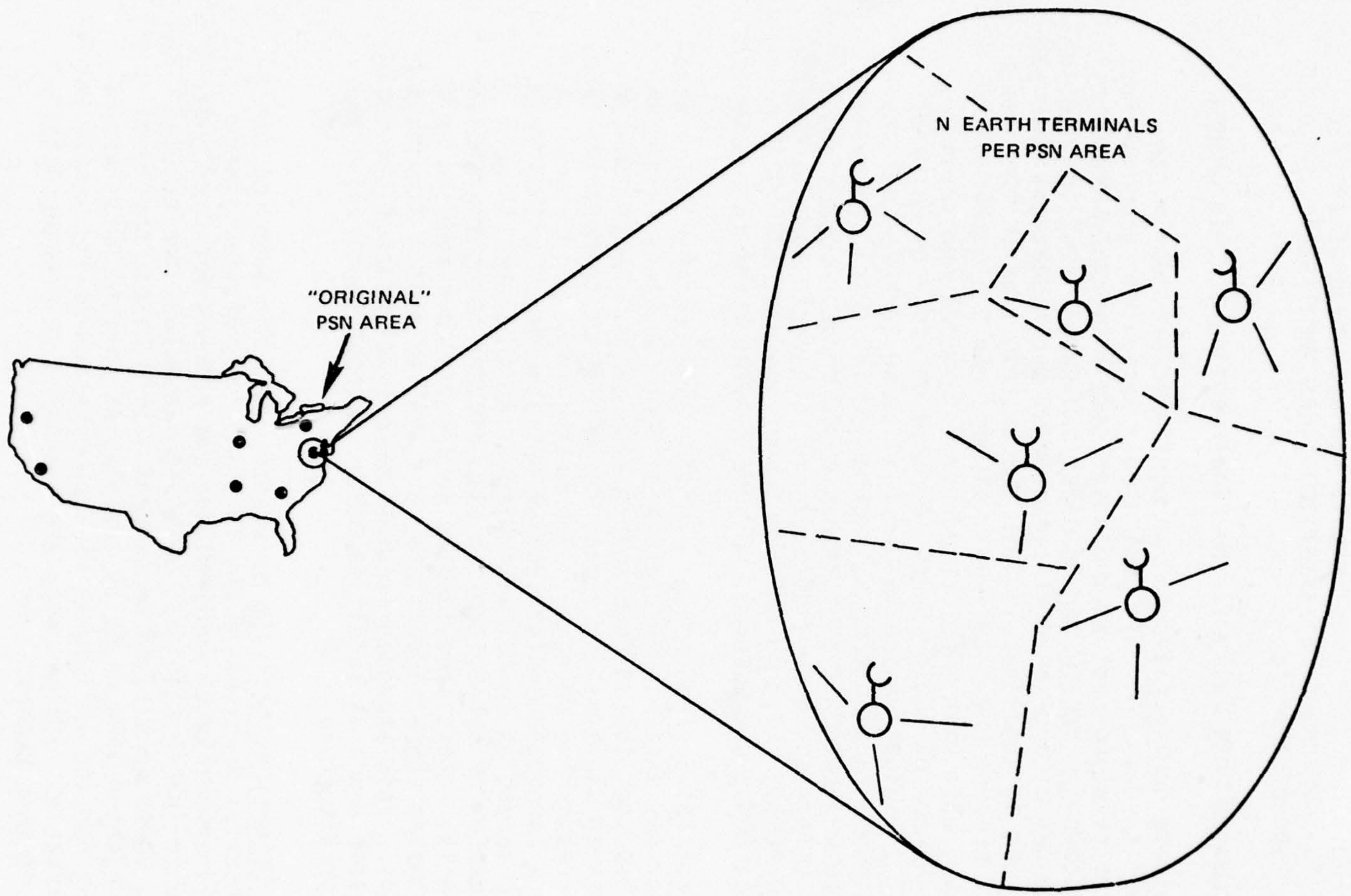


Figure 2. Subdivision of Original PSN Areas

2. ANALYSIS CRITERIA

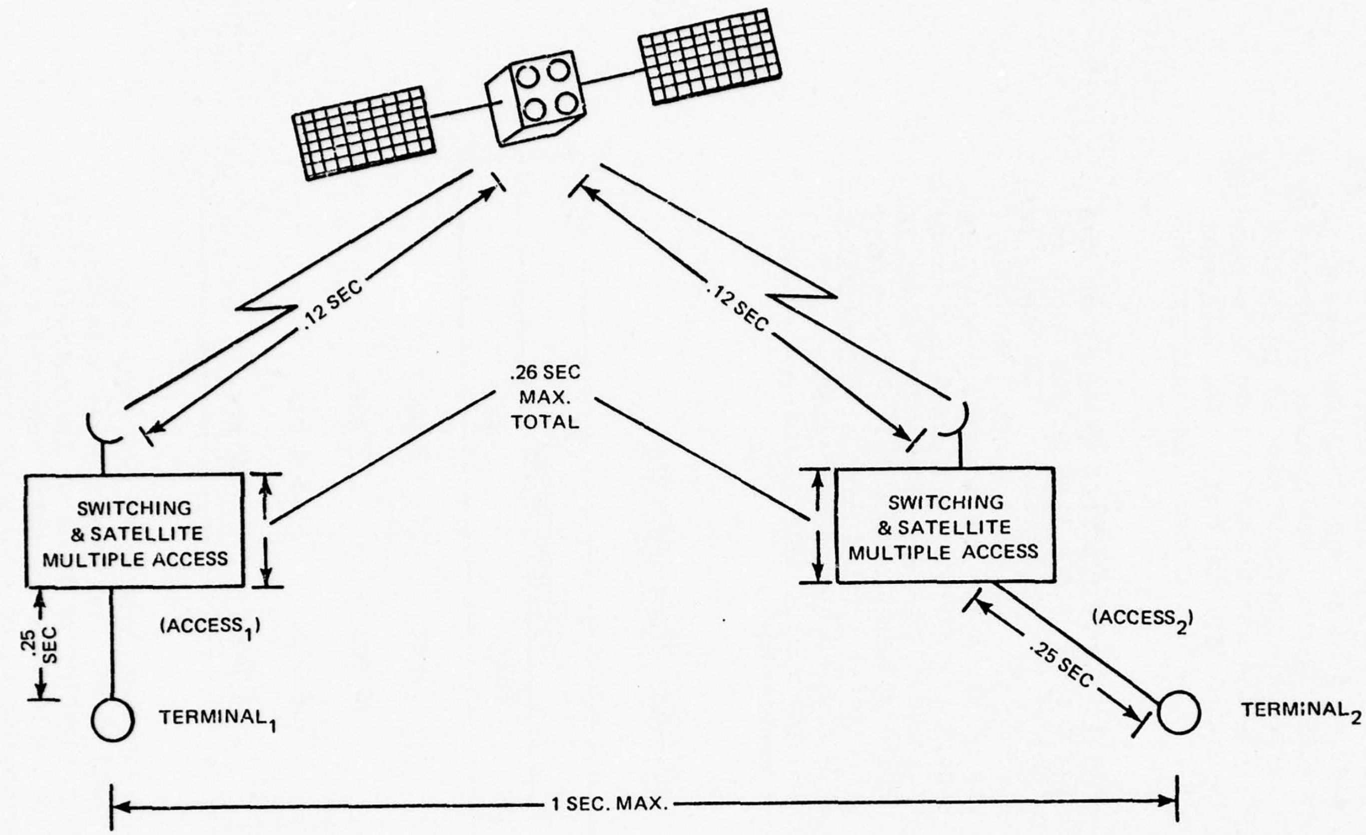
a. General. While the overall system specification for the 1990 IAS has not yet been formulated, a similar specification does exist for the AUTODIN II packet switched system. Performance criteria for AUTODIN II are felt to be a reasonable approximation to those that will ultimately apply to the IAS, and are therefore used as a baseline for the analysis of satellite system applicability. The following paragraphs summarize important criteria and their implications for IAS satellite transmission.

b. Response Time. Response time or delivery delay is defined as the lapsed time from the start of a source transaction until the last transaction bit is received at the destination. The delays pertain to transactions of average length and are indicated in Table I. Limitations imposed on the use of satellite transmission result when round-trip satellite delays (both transmission delay and delay resulting from the multiple access/demand assignment technique) exceed the allowable specified delay. Where no acceptable satellite technique can be found or developed, terrestrial transmission may be required, or a longer delay (and possible reduced system performance) must be accepted. Figure 3 illustrates the limitations on the system delay budget imposed by satellite transmission.

TABLE I. DELIVERY DELAY CRITERIA

Type of Transmitter	Delivery Delay	
	Mean	Max
Interactive	1 sec.	2 sec.
Query/Response	36 sec.	2 min.
Bulk 1 or Narrative	1.6 min.	6.4 min.
Bulk 2	4 hrs.	12 hrs.

c. Error Rate. The user-to-user undetected bit error rate through the network is specified at 10^{-12} or less. While satellite link error rates are generally superior to those of terrestrial links, error detection and correction techniques are still required to meet the stated objective. Moreover, the round-trip delay inherent in satellite links limits the choices in error control protocols.



$T_{DELIVERY} = T_{ACCESS_1} + T_{BACKBONE} + T_{ACCESS_2} + T_{SWITCHING} + T_{MULT.\ ACCESS}$

FOR 2400 BPS ACCESS LINES AND 600 BIT MESSAGES: $T_{ACCESS_1} = T_{ACCESS_2} = .25$ SEC.

FOR SATELLITE TRUNK, $T_{BACKBONE} = .24$ SEC.

$\therefore$ SWITCHING AND MULTIPLE ACCESS DELAY CANNOT EXCEED .26 SEC.

Figure 3. Impact of Satellite Transmission on the Delivery Delay Budget

d. Relative Network Volume. The relative transaction volume (in bits) through the network in the busy hour is:

- Bulk 1: 85 percent
- AUTODIN I Trunking: 9 percent
- Narrative: 5 percent
- Interactive: <1 percent
- Query/Response: <1 percent.

While Bulk I is the largest category, the most stringent delivery requirements are imposed by the interactive traffic. Interactive traffic is small in terms of the number of bits; however, it represents a substantial proportion of the number of messages generated and is time critical because it usually involves computer/computer or human/computer interaction or high level command and control applications. The satellite systems must, therefore, be designed to accommodate interactive traffic as a primary user wherever possible.

e. System Availability. Availability is defined as the percentage of time that any pair of users are able to communicate with each other through the network with at least the following capability:

- Bit error rate of 10^{-12} or less
- Delivery delay not to exceed that indicated in Table I.

User availability should be 99 percent with a single access to a PSN and 99.95 percent availability for users who connect to two PSNs.

Availability is closely related to survivability which is an issue in military satellite communications because of satellite susceptibility to destruction or jamming. The packet-switched communications discipline is ideally suited to survivable terrestrial transmission due to its inherent advantages for alternate routing at switching nodes. In a satellite transmission system, however, the use of packet techniques does not, in itself, increase survivability. A number of satellite multiple access techniques (notably CDMA and various spread-spectrum approaches) do provide resistance to jamming. These have been analyzed in depth in other studies and will not be addressed here; however, the implications of survivability will be given attention in this report as they apply to candidate satellite broadcast techniques.

f. Throughput. An important consideration in meeting the technical criteria of the IAS is the throughput capabilities of its elements. As a part of the traffic projections made later in the report, estimates of traffic throughput for individual earth stations are made. In general, a transmission oriented viewpoint has been adopted, where link capacities are of concern, rather than an orientation toward the total traffic capabilities of switches. It is assumed that the switches will have sufficient capacity to meet overall system technical objectives for the switching subsystem. Transmission system analysis is thus directed toward contributing to overall system objectives.

III. SYSTEM CONFIGURATION AND TRAFFIC REQUIREMENTS

III. SYSTEM CONFIGURATION AND TRAFFIC REQUIREMENTS

1. GENERAL

As packet switching is introduced into the DCS, data traffic is expected to exhibit a rapid increase. Two primary factors behind these increases are the increase in the number of worldwide subscribers from 1500 currently to approximately 4000 in 1990. Likewise, the number of Automated Message Processing Exchanges (AMPEs) used by the services (such as the Navy's Local Digital Message Exchange) will continue to increase and generate additional traffic. Table II illustrates these changes, as well as the projected number of switch nodes for 1977, 1980, and 1990. Overall traffic volume is also presented for comparison.

As discussed earlier, traffic requirements for the 1990 IAS were developed by relating present AUTODIN traffic to estimated packet-switched traffic loads for Phase I of AUTODIN II, and then extrapolating using assumed growth factors to postulate 1990 IAS traffic loads. This chapter describes the steps of this process in detail and presents traffic data developed for the balance of this analysis.

2. PRESENT NEEDLINES AND TRAFFIC

The present AUTODIN I system is comprised of seventeen AUTODIN Switching Centers (ASCs), with eight located in CONUS, six in the Pacific area and three in Europe. These switches are connected by dedicated transmission channels as shown in Figure 4. Routing tables establish primary and alternate routes through the network for messages between any two given ASCs.

For the purpose of IAS traffic projections, however, the current network configuration and routing must be ignored and only the source to destination (needline) traffic loads considered. Computer printouts were obtained from DCA (RADAY 188, 1977) which present needline loads by routes. Analysis of these printouts has resulted in the traffic matrix shown in Table III. This matrix presents current AUTODIN traffic worldwide expressed in line blocks over a 24 hour period, and reveals a total system load of over 8 million line blocks per day.

3. PROJECTED NEEDLINES AND TRAFFIC FOR AUTODIN-II PHASE I

Phase I of AUTODIN II will introduce Packet Switch Nodes (PSNs), collocated with certain CONUS AUTODIN switching centers. A data base has been compiled by DCA of projected AUTODIN II traffic

TABLE II. AUTODIN SYSTEM GROWTH

CHARACTERISTICS	1977	1980*	1990
. SUBSCRIBERS			
- CONUS	900	1200	2400
- EUROPE	200	250	500
- PACIFIC	400	500	1000
Total:	1500	1950	3900
. SWITCH LOCATIONS			
- CONUS	8	7	7
- EUROPE	3	3	3
- PACIFIC	6	5	5
Total:	17	15	15
. TOTAL SYSTEM BUSY HOUR TRAFFIC			
- CONUS	8.5×10^8 bits	9.1×10^9 bits	1.8×10^{10} bits
- EUROPE	1.2×10^8 bits	1.6×10^9 bits	3.2×10^9 bits
- PACIFIC	1.1×10^8 bits	1.3×10^9 bits	2.6×10^9 bits
Total:	1.1×10^9 bits	1.2×10^{10} bits	2.4×10^{10} bits

* 1980 Figures Represent Aggregate of DIN I and DIN II.

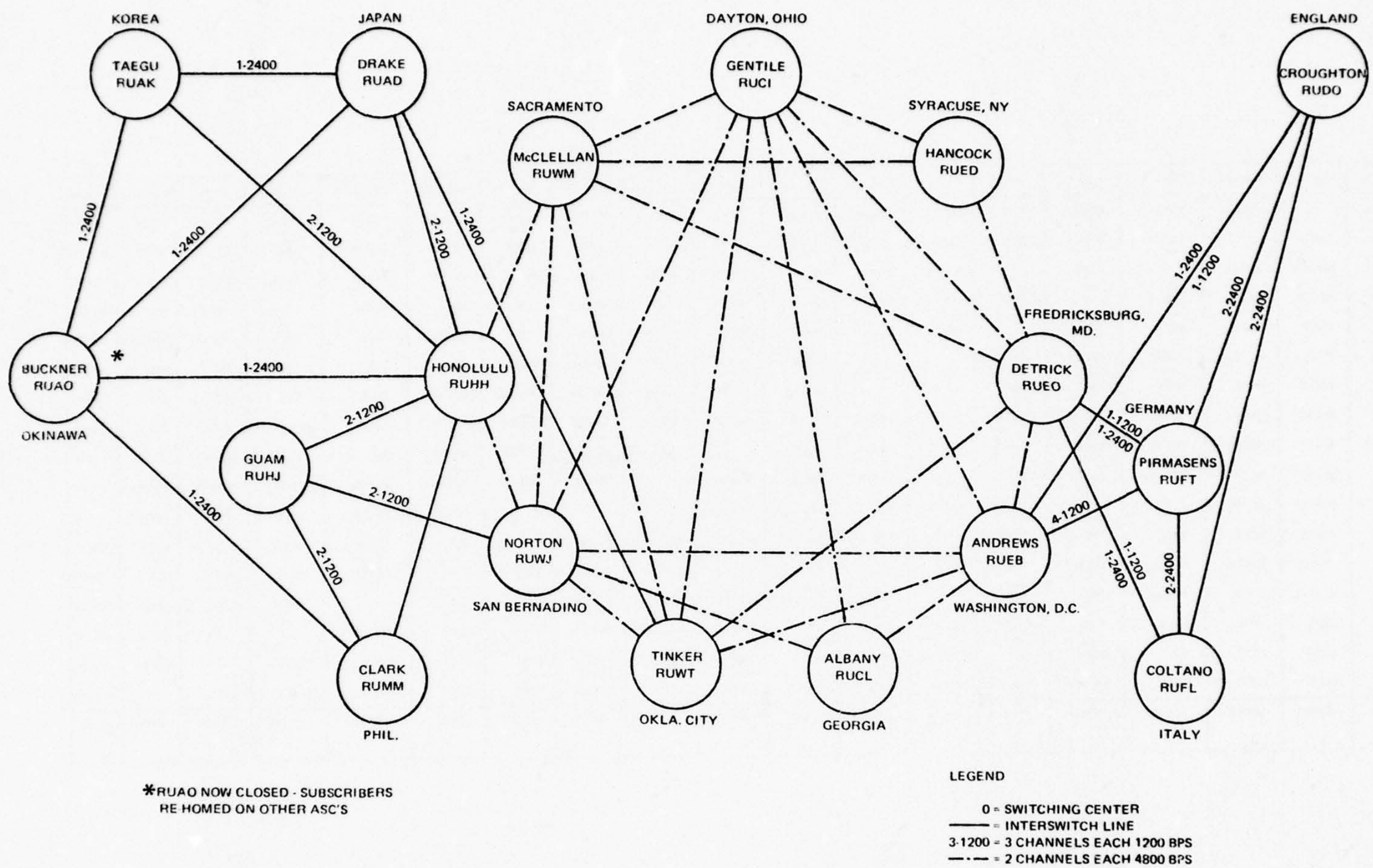


Figure 4. Present AUTODIN System Configuration

TABLE III. CURRENT AUTODIN NEEDLINE TRAFFIC LOADS
(Line Blocks per Day)

FROM \ TO	RUAD	RUAK	RUAO	RUCI	RUCL	RUDO	RUEB	RUED	RUEO	RUFL	RUFT	RUHH	RLHJ	RUMM	RUWJ	RUWM	RUWT	TOTAL
RUAD	–	2,323	4,220	5,821	2,403	742	13,467	4,109	7,095	509	318	15,895	2,498	6,389	4,866	5,069	9,335	85,059
RUAK	8,434	–	3,590	5,553	1,914	176	3,684	13,446	15,892	136	263	23,032	694	5,890	7,720	3,412	9,397	103,233
RUAO	5,370	2,171	–	11,666	5,477	5,270	4,008	61,906	31,848	105	428	27,593	4,797	11,835	3,404	3,531	4,282	183,691
RUCI	5,339	5,137	5,208	–	84,671	11,470	47,418	102,287	80,167	14,146	19,605	11,021	1,738	4,880	349,315	28,331	111,431	882,224
RUCL	2,922	2,198	2,323	112,287	–	7,238	139,976	67,471	102,545	9,689	7,256	6,537	4,478	3,591	79,760	12,478	77,051	637,800
RUDO	1,685	227	3,437	14,943	15,560	–	90,734	17,326	45,165	50,790	79,961	1,980	1,534	563	8,184	5,026	26,630	363,745
RUEB	9,940	6,661	4,529	132,940	81,593	39,628	–	67,420	113,407	16,177	22,734	50,025	10,396	8,378	65,233	50,969	86,026	766,056
RUED	2,733	55,056	3,200	160,719	69,690	14,980	39,603	–	90,063	16,350	30,100	8,717	2,235	3,177	141,045	36,415	91,175	715,708
RUEO	17,757	17,781	8,917	187,475	141,762	41,016	125,510	106,612	–	46,958	34,778	33,938	7,547	10,019	85,025	64,299	133,125	1,062,519
RUFL	544	273	341	18,680	13,327	29,292	20,017	12,581	63,890	–	57,354	1,719	318	352	8,833	4,605	24,388	256,514
RUFT	523	641	228	15,973	14,059	38,398	47,233	10,958	39,737	50,010	–	2,408	1,367	241	10,424	3,566	21,537	257,303
RUHH	21,570	8,188	12,649	7,603	8,528	1,349	20,449	20,129	25,057	1,580	317	–	10,106	23,270	24,584	35,150	17,560	238,089
RUHJ	4,808	1,766	6,707	2,604	1,585	687	4,375	8,387	10,570	440	567	10,790	–	9,852	7,364	5,506	3,716	79,724
RUMM	4,705	1,521	8,068	4,876	1,464	543	2,934	7,655	10,006	43	69	21,983	11,259	–	15,829	5,949	11,986	108,920
RUWJ	6,247	4,442	6,760	90,141	66,737	8,260	47,528	66,345	53,100	9,758	29,184	24,674	14,060	7,895	–	82,027	145,098	662,256
RUWM	6,609	4,341	5,398	57,163	32,377	5,521	34,215	87,229	70,351	5,651	2,877	15,277	10,637	13,705	125,501	–	77,053	553,855
RUWT	4,500	8,421	3,364	179,504	96,367	17,423	180,555	101,902	72,540	20,377	14,093	12,662	5,385	6,466	34,803	199,501	–	1,057,863
TOTAL	103,686	71,577	78,909	1,007,948	637,514	221,993	821,706	755,763	831,433	242,719	299,904	268,251	89,079	116,503	1,071,890	545,894	849,790	8,014,559

requirements and needline traffic loads for the eight CONUS ASC locations. These were presented in a scenario contained in the AUTODIN II "Type A" Specification. The scenario traffic data provided an estimate of traffic in a packet switched network. This was compared directly to current AUTODIN traffic in CONUS and the relationships thus developed were used to estimate traffic in a worldwide packet switched network, covering the same areas as the current worldwide AUTODIN.

While the ratios of AUTODIN I traffic to AUTODIN II traffic varied significantly by needline, an overall average was used for estimation purposes. It was found that, on the average, each 1000 daily AUTODIN I line blocks translated to 380 bits per second of AUTODIN II traffic.

Intra-node traffic was estimated at 30 percent of the inter-node traffic originated at each PSN. This figure was obtained by determining total originated inter-node traffic for each CONUS AUTODIN II PSN (from DCA estimates contained in the AUTODIN II data base for CONUS destinations, and from the above ratio estimation technique for overseas destinations). The resulting inter-node total was then compared with DCA estimates for intra-node traffic at each originating node.

In addition to the larger traffic load of AUTODIN II, changes in network topology will affect needline configurations and traffic. In the estimation of AUTODIN II, traffic from the ASC on Okinawa (RUAO) has been re-homed into Japan (RUAD), reflecting the closing of the former. Likewise, a re-homing of traffic in CONUS was performed to reflect the elimination of one CONUS ASC. It was assumed in this study that the Ft. Detrick ASC traffic would be divided evenly between Gentile and Hancock, as Ft. Detrick is roughly equidistant from the latter two ASCs, and Andrews already has a very high subscriber load. Table IV presents the resultant needline traffic loads for a worldwide version of AUTODIN II in the 1980 time frame. This projection reveals a total system traffic load of over 3 megabits per second in the busy hour, with 77 percent of the total representing inter-node traffic.

4. ESTIMATED 1990 IAS NEEDLINES AND TRAFFIC

Because the 1990 IAS configuration has not yet been established, it was assumed that IAS node locations will closely parallel those of AUTODIN. This means that traffic volumes are associated with a given geographical area roughly equivalent to the area served by each ASC or 1980 Packet Switch Node (PSN). Although this may not prove to be the case, it provides a convenient basis for analysis and will, in fact, be modified as alternative system configurations are examined in Chapter VI.

TABLE IV. PROJECTED 1980 WORLDWIDE AUTODIN II NEEDLINES AND TRAFFIC LOADS

FROM \ TO	RUAD	RUAK	RUHJ	RUCI	RUCL	RUDO	RUEB	RUED	RUFL	RUFT	RUHH	RUMM	RUWJ	RUWM	RUWT	TOTAL TRAFFIC	INTER-NODE
RUAD	31.44	1.70	2.75	13.97	2.98	2.27	6.60	32.29	0.23	0.28	16.42	4.82	3.13	3.24	5.14	127.76	95.82
RUAK	4.55	13.00	0.26	5.10	0.72	0.07	1.39	8.08	0.05	0.10	8.70	2.22	2.92	1.29	3.55	52.00	39.00
RUHJ	4.35	0.67	10.04	2.98	0.60	0.26	1.65	5.17	0.17	0.21	4.07	3.72	2.78	2.08	1.40	40.15	30.11
RUCI	9.03	5.30	2.09	72.69	22.76	12.08	52.72	17.83	14.21	13.97	10.57	3.73	17.02	30.01	43.35	327.36	254.67
RUCL	1.98	0.83	1.70	14.21	24.65	2.73	38.66	12.63	3.66	2.74	2.47	1.36	15.84	7.45	60.57	191.67	166.82
RUDO	1.94	0.09	0.58	14.17	5.88	45.78	34.26	15.07	19.18	30.19	0.75	0.21	3.09	1.90	10.05	183.13	137.35
RUEB	5.46	2.52	3.93	45.86	54.94	14.96	214.28	70.28	6.11	8.58	18.89	3.16	28.89	29.00	53.71	560.57	346.29
RUED	7.28	5.44	2.27	18.43	13.17	13.41	82.79	37.85	15.04	17.94	9.70	3.09	10.83	14.70	35.25	287.19	249.34
RUFL	0.34	0.10	0.12	19.11	5.03	11.06	7.56	16.81	32.29	21.66	0.65	0.13	3.34	1.74	9.21	129.15	98.86
RUFT	0.29	0.24	0.52	13.53	5.49	14.50	17.84	11.65	18.88	32.45	0.91	0.09	3.94	1.35	8.13	129.81	97.36
RUHH	12.92	3.09	3.82	7.60	3.22	0.51	7.72	12.33	0.06	0.12	29.97	8.79	9.28	13.27	6.63	119.87	89.90
RUMM	4.83	0.57	4.26	3.73	0.55	0.21	1.10	4.78	0.02	0.03	8.30	13.71	5.98	2.25	4.53	54.85	41.14
ROWJ	4.92	1.67	5.31	10.30	21.66	3.12	36.59	16.36	3.68	11.02	9.32	2.98	17.90	23.87	19.59	188.29	170.39
RUWM	4.52	1.64	4.02	13.02	10.50	2.08	22.42	11.87	2.13	1.09	5.77	5.18	14.72	53.93	35.26	188.14	134.21
RUWT	2.97	3.18	2.03	65.32	76.91	6.58	73.58	53.99	7.69	5.32	4.78	2.94	37.87	76.31	155.65	594.62	438.97
																3,174.56	2,388.23

SHADED AREAS BASED ON AUTODIN II SCENARIO IN "A" SPECIFICATION
NOTE – FORMER RLEO (FT. DETRICK) TRAFFIC SPLIT EVENLY BETWEEN RUCI (GENTILE) AND RUED (HANCOCK)
NOTE – FORMER RUAC (OKINAWA) TRAFFIC INCLUDED IN RUAD (JAPAN)

With 1980 AUTODIN II traffic estimates as a starting point, IAS traffic in 1990 was projected. Although the initial growth of AUTODIN II traffic is expected to be dramatic, it is already reflected in the 1980 estimates of the DCA data base. With the basic packet switched capability in place and initial usage established in 1980, a more orderly growth can be expected to 1990. A post-1980 annual traffic growth rate of seven percent was assumed for all nodes, resulting in an overall doubling of network traffic by 1990.

The projected traffic load in Kb/sec during the busy hour for the 1990 IAS is presented in Table V. It will be noticed that current AUTODIN routing indicators have been used to identify node locations. Also, the order of presentation is changed from previous matrices to reflect the geographic location of the nodes. This will aid subsequent analysis when satellite coverage areas must be considered. Total traffic is projected to be 6 megabits per second in the busy hour.

TABLE V. PROJECTED 1990 IAS NEEDLINES AND TRAFFIC LOADS

	RUAD	RUAK	RUMM	RUHJ	RUHH	RUWM	RUWJ	RUWT	RUCI	RUCL	RUEB	RUED	RUDO	RUFT	RUFL	TOTAL TRAFFIC	INTER-NODE
RUAD	63.88	3.40	9.64	5.50	32.84	6.48	6.26	10.28	27.94	5.96	13.20	64.58	4.54	0.56	0.46	255.52	191.64
RUAK	9.10	26.00	4.44	0.52	17.40	2.58	5.84	7.10	10.20	1.44	2.78	16.16	0.14	0.20	0.10	104.00	78.00
RUMM	9.66	1.14	27.42	8.52	16.60	4.50	11.96	9.06	7.46	1.10	2.20	9.56	0.42	0.06	0.04	109.70	82.28
RUHJ	8.70	1.34	7.44	20.08	8.14	4.16	5.56	2.60	5.96	1.20	3.30	10.34	0.52	0.42	0.34	80.30	60.22
RUHH	25.84	6.18	17.58	7.64	59.94	26.54	18.56	13.26	15.20	6.44	15.44	24.66	1.02	0.24	1.20	239.74	179.80
RUWM	9.04	3.28	10.36	8.04	11.54	107.86	29.44	70.52	26.04	21.00	44.84	23.74	4.16	2.18	4.26	376.30	268.44
RUWJ	9.84	3.34	5.96	10.62	18.64	47.74	35.80	39.18	20.60	43.32	73.18	32.72	6.24	22.04	7.36	376.58	340.78
RUWT	5.94	6.36	4.58	4.06	9.56	152.62	75.74	311.30	170.64	153.82	147.16	107.98	13.16	10.64	15.38	1,189.24	877.94
RUCI	18.06	10.60	7.46	4.18	21.14	60.02	34.04	86.70	145.38	45.52	105.44	35.66	24.16	27.94	28.42	654.72	509.34
RUCL	3.96	1.66	2.72	3.40	4.44	14.90	31.68	121.14	28.42	49.70	77.32	25.26	5.46	5.48	7.32	383.36	333.66
RUEB	10.92	5.04	6.32	7.86	37.78	58.00	57.78	107.42	91.72	109.88	428.56	140.56	29.92	17.16	12.22	1,121.14	692.58
RUED	14.56	10.88	6.18	4.54	19.40	29.40	21.66	70.50	36.86	26.34	165.58	75.70	26.82	35.88	30.08	574.38	498.68
RUDO	3.88	0.18	0.42	1.16	1.50	3.80	6.18	20.10	28.34	11.76	68.52	30.14	91.56	60.38	38.36	366.28	274.72
RUFT	0.58	0.48	0.18	1.04	1.82	2.70	7.88	16.26	27.06	10.98	35.68	23.30	29.00	64.90	37.76	259.62	194.72
RUFL	0.68	0.20	0.26	0.24	1.30	3.48	6.68	18.42	38.22	10.06	15.12	33.62	22.12	43.32	64.58	258.30	193.72
																6,349.18	4,776.52

IV. TERRESTRIAL TRANSMISSION, 1990

IV. TERRESTRIAL TRANSMISSION, 1990

1. GENERAL

Any projection or evaluation of future terrestrial communications systems must consider two important factors, technology and tariffs. The future system costs resulting from these factors can significantly influence the overall terrestrial/satellite mix for the 1990 IAS. This chapter will examine developments and trends in terrestrial communications which will be of major importance in the overall IAS system implementation.

2. TECHNOLOGY

The primary trend in terrestrial transmission over the next decade will be increased use of digital transmission techniques. Although Pulse Code Modulation (PCM) and the T-carrier multiplex structure has existed for voice for some years, the majority of access lines and virtually all long-haul circuits are implemented using analog techniques. As data communication has become increasingly more in demand, especially for high speed, interactive computer networks, there has been a great deal of pressure to develop innovative digital transmission services. The DATRAN network (now part of Southern Pacific Communications Corporation) is a good example of this. In addition, services such as Telenet's packet switched system and AT&T's Data Under Voice (DUV) and Digital Data Service (DDS) also serve to illustrate the rapid growth in data communications and the attendant need for digital transmission.

To meet this need, industry has turned to techniques such as digital microwave and fiber optics to provide the facilities required to efficiently handle large amount of data traffic. Fiber optics has seen the most dramatic advancements in recent years, with the development of low loss fibers, laser modulators and detectors, and economic methods for connecting and splicing individual fibers.

Benefits to be gained through the use of fiber technology include:

- Increased capacity per unit size
- Reduced susceptibility to EMI
- Improved reliability
- Reduced life cycle costs.

In 1990, it is expected that fiber optics will be commonplace for local trunking applications, high speed data links of over a few hundred feet, and for some limited long-haul links. The current amount of installed analog/copper plant, however, will prevent the domination of fiber optics until well into the 21st century.

3. TARIFF TRENDS

One of the most frustrating issues in communications planning today is the inability to project tariff costs. For a communications manager, this means department budgets can be quickly overrun by an unforeseen rate hike. This issue is extremely complicated and is continually changing. During the past ten years the Federal Communications Commission (FCC) has attempted to restrict abrupt tariff changes and assure that each new revision is justified.

The main issue is providing a service cost or tariff that is directly related to the plant inventory. The Bell System is currently trying to define this area and will continue to do so into the future. As an example of Bell System rate implications and how they indicate the uncertainty of projecting future costs, a summary of some of the major issues is presented in Table VI.

4. COST

The cost of a particular terrestrial service is directly related to the topology, the bandwidth, and the grade of service required. Therefore, the assumptions used concerning the circa 1990 network configuration are critical to cost development of that system. These assumptions were presented in Chapter I. Because of the uncertainties highlighted in Table VI, terrestrial costs were evaluated assuming both the continued existence of TELPAK as well as its elimination. Chapter VI develops specific cost estimates for IAS terrestrial transmission.

TABLE VI. TERRESTRIAL TRANSMISSION REGULATORY ISSUES

. Since 1971, the FCC has supported competition with the Bell System by "interconnect" firms and specialized common carriers; however, the Commission has ruled that AT&T may impose "connection charges" and require an interconnect vendor to certify his equipment.
. In 1976, the FCC ruled that AT&T rates and services were unlawful. This ruling directly affects TELPAK, WATS, MPL, and DDS services and tariffs.
. Eliminating the TELPAK offering for "unlawful discrimination" of rates between hi/lo and multipoint tariffs would mean a 25% - 45% increase in current telecommunication costs for many corporations and agencies.
. Users are caught between choosing current AT&T or common carrier offerings and unknown future offerings (or lack thereof) resulting from political pressures for more competition, regulatory uncertainty, and special interest groups.

V. SATELLITE SYSTEMS TECHNOLOGY, 1990

V. SATELLITE SYSTEMS TECHNOLOGY, 1990

1. GENERAL

When considering candidate satellite applications for the 1990 IAS, the technology which will be available at that time must be considered. Satellite systems divide naturally into the "Space Segment," which includes the satellites themselves as well as launch vehicles, and the "Ground Segment," encompassing earth stations and their various subsystems. This chapter will discuss the developments in each of these areas and the capabilities expected to exist by 1990.

2. SPACE SEGMENT

a. Satellites. The implementation and launch of a communications satellite brings together a wide diversity of technologies. Of most immediate interest to the communication system engineer is the capability of the satellite to handle a large number of diverse users (earth stations). Satellites have progressed from single, broadband, low power transponders (such as "Early Bird") capable of supporting only a single link between two large earth stations, to today's satellites using shaped antenna beams, multiple transponders of comparatively narrow bandwidth and high effective radiated power. These satellites can support hundreds of accesses by moderately sized earth terminals, and special systems can even support small, mobile terrestrial stations such as those used in the MARISAT system.

The trend has been toward higher EIRP satellites using multiple transponders and multiple beam antennas to enable a large number of small earth stations to share satellite capacity. In military applications, efforts have been toward use of steerable beam antennas to provide for contingency operations and to provide a certain degree of interference protection through null steering.

In the 1990 time frame the DSCS III and INTELSAT V satellites will be operational. Technical parameters of these satellites are shown in Table VII. In addition, development of the next generation of satellites will be well underway. These satellites are expected to include steerable lens antennas (as on DSCS III), onboard signal processing (especially in terms of beam switching and spread spectrum techniques), and 30/20 GHz capability. These advanced systems are not expected to be operational until the mid 1990s, however, primarily due to difficulties in developing space-qualified hardware for 30/20 GHz. Therefore, for the purpose of this analysis, the basic capabilities represented by DSCS III and INTELSAT V have been assumed.

TABLE VII. SPACECRAFT: 1985-1990

Characteristics	DSCS III	INTELSAT V
Frequencies Used	7.25 - 8.4 GHz UHF	4/6 GHz 14/11 GHz
Number of Transponders	6 (7/8 GHz) 1 (UHF)	21 (4/6 GHz) 6 (14/11 GHz)
Bandwidth per Transponder	50-85 MHz (7/8 GHz) single channel (UHF)	40, 80 MHz (4/6 GHz) 80, 240 MHz (14/11 GHz)
Antennas	Two 19 beam waveguide lens antennas (transmit) One 61 beam waveguide lens antenna (receive) Two earth coverage horns One gimballed dish antenna (transmit) Earth coverage UHF antennas	Earth coverage horns Dual hemispheric reflectors Dual zone reflectors } 4/6 GHz Dual steerable spot reflectors (14/11 GHz)
EIRP	25 - 44 dBW depending on transponder and antenna	22 - 29 dBW (4/6 GHz) 41 - 44 dBW (14/11 GHz)

b. Launch Vehicles. Launch vehicles for satellites depend greatly on the number of satellites to be launched, the orbital altitude desired, and the total payload weight. Launch vehicles for current geosynchronous communication satellites have been of the Atlas-Centaur and Delta variety, with typically two satellites being launched simultaneously. By 1990, the Space Shuttle is expected to be used for placing satellites into a low level orbit from which they will be transferred to synchronous orbit via expendable orbit insertion vehicles or a reusable space tug.

Typical launch costs using current vehicles run in the vicinity of \$15 to \$25 million for synchronous orbit, depending on payload weight. Use of the space shuttle is expected to reduce these costs to the \$7 to \$15 million range (1977 dollars).

3. GROUND SEGMENT

a. Frequency Bands. Earth station technology is currently well established at 4/6 GHz and at X-band (7/8 GHz). The move to higher frequencies (14/11 GHz and 30/20 GHz) has spurred development in earth station hardware for these bands. By 1990, it is expected that these developments will be well along, in consort with the development of spacecraft assets.

b. Antennas. Overall earth station requirements are affected to a great extent by spacecraft capabilities. The development of high EIRP, multibeam spacecraft make the use of a large number of smaller, less costly, earth stations possible, as opposed to the few, very large terminals used in the past. As an example, a standard INTELSAT earth station will range from \$10 million to \$40 million while a small (10 meter antenna) earth terminal will cost from \$100K to \$200K. At higher frequencies, smaller antennas can be used, although surface tolerances become more stringent. The 4/6 GHz domestic satellite systems currently use antennas of 5 to 10 meters in diameter, and in the 14/11 GHz band, Satellite Business Systems is planning on employing 5 and 7 meter antennas at its customers' locations.

c. Multiple Access. Technical and cost considerations favor TDMA as the future multiple access technique for satellite communications, especially in military applications where transmitted information is primarily digital. However, a limiting factor in the use of TDMA in the 7/8 GHz band is the difficulty encountered in obtaining terrestrial frequency coordination for the bandwidths required by the high burst rates used in many TDMA approaches. In many areas of the world, this frequency range is shared with fixed terrestrial links, and satellite systems must be closely coordinated to avoid interference (a problem encountered by many commerical satellite systems operating at 4 and 6 GHz).

These problems can be avoided by using the satellite-only frequencies at 30/20 GHz. However, a system operating at these frequencies would require dual (or even triple) diversity earth stations separated by several kilometers and connected by microwave links to overcome the effects of rainfall attenuation. Also, as was mentioned previously, it is not expected that an operational 30/20 GHz system will be available by 1990. Thus, TDMA operation will be limited to locations where sufficient bandwidth (and a common center frequency) can be cleared at 7/8 GHz.

Many demand assignment techniques are currently being considered for implementation in TDMA type systems. Most are based on packet technology and can be considered derivatives of the ALOHA packet radio techniques. Because of the tendency of many of the packet radio techniques to become unstable under heavy load, methods of ensuring stability and increasing throughput (such as Round Robin Reservation and Conflict Free ALOHA) have been postulated which overcome these problems at the expense of greater complexity. The cost of providing such capability has not been accurately determined, however, given a basic TDMA terminal, it is felt that the implementation of any of the broadcast demand assignment techniques could be accommodated within a budget of $20K-$25K, using a minicomputer or microprocessor and related interfaces.

d. Cost. The overall cost of earth stations can best be estimated by considering basic transmission performance parameters such as antenna size, receiver noise temperature, and transmitter power, as well as common equipment cost. With these establishing a baseline cost for the station, other items such as support equipment and manpower may be determined to arrive at overall system cost. Specific earth station cost estimates are developed in the next chapter.

One item to which satellite system cost is very sensitive is the cost of operation and manning the earth stations. While current practice requires a 20 man-year allocation to each earth station, technology now permits "stand-alone" stations which require only periodic maintenance. Depending on required station size and complexity, this has the potential of reducing O&M costs of satellite earth stations significantly. The actual cost impact of such reductions are discussed in more detail in the next chapter.

VI. IAS TRANSMISSION ALTERNATIVES, 1990

VI. IAS TRANSMISSION ALTERNATIVES, 1990

1. GENERAL

This chapter considers satellite transmission implementation alternatives for the worldwide IAS of 1990. Several rules were established and assumptions made regarding the system candidates, and a parametric approach was adopted for evaluating the applicability of satellite versus terrestrial transmission as a function of the number of earth stations employed.

The basic assumption adopted, which was described earlier, was that overall IAS traffic demand is related to current AUTODIN and projected CONUS AUTODIN II traffic by linear relationships (refer to Chapter III for a more detailed discussion of IAS traffic projections). It was further assumed that geographical areas represented by the current AUTODIN ASCs would serve as a basis for grouping IAS traffic.

Satellite assets were assumed to be of the DSCS III and INTELSAT V family. If a more sophisticated space segment is employed in 1990, this assumption may result in somewhat conservative results. Earth stations were assumed to be dedicated to IAS traffic and were thus located at IAS switching nodes. No evaluation was made of the consequences of locating earth stations to serve an "integrated" voice and data satellite system although some of the implications of such an integration are presented in the discussions which follow.

The remainder of this chapter will address the various aspects of the candidate implementations and will evaluate their applicability and impact on the 1990 IAS.

2. TOPOLOGY

a. Satellite Network. The assumed 1990 IAS topology reflects an organization of system assets into "access" areas and a "backbone" area. The access area represents individual user terminals and host computers and their connections to packet switch nodes (PSNs). Included in the access area would be any multiplexor or concentrator functions used to achieve transmission economies, but which perform no terminal-to-terminal switching (none were assumed for this study, however).

The "backbone" area represents the lateral connection of PSNs, providing connectivity between subscribers in different access areas. In a satellite sense, however, the term "backbone" is a

misnomer. Broadcast satellite networks can be envisioned more as using a "node-in-the-sky" which all users share rather than a line or transmission system which is constrained geographically.

For this study, a configuration based on the current AUTODIN was assumed, wherein earth stations are located at each PSN, thereby providing all inter-PSN transmission. (If earth stations were not co-located with PSNs, as might be the case in an integrated voice and data system, additional terrestrial line costs could be incurred to link PSNs with their respective earth stations.) PSNs were grouped within satellite coverage areas (DSCS III space segment assumed), with designated earth stations within the overlapping coverage areas of two satellites providing a "tandem" capability for traffic between PSNs in different satellite regions. Figure 5 shows the IAS traffic matrix presented previously, with nodal locations arranged by satellite area. As can be seen, the PSNs at Hawaii (RUHH) and McClellan (RUWM) provide connectivity between the West Pacific satellite area and the East Pacific area (which also covers CONUS). Likewise, Albany, Georgia (RUCL) and Andrews (RUEB) provide connectivity between the East Pacific satellite area and PSNs in the Atlantic area.

b. Terrestrial Network. The terrestrial network is designed to complement the satellite network, providing connectivity between subscribers and nodes which are not served by an earth station.

For analysis purposes, the terrestrial network assumed for 1990 consists of a backbone of 34 wideband (56 Kb/sec) trunks connecting 15 PSNs, and access lines (unspecified in number) which are proportional to the number of subscriber terminals. The introduction of a minimal satellite system (15 earth stations) eliminates the terrestrial backbone. The terrestrial access network is then altered as satellite earth stations are added, with the traffic from each original PSN area uniformly divided between N nodes in that area. Terrestrial systems were analyzed as a function of the relative mix of low speed(<1800 bps) and high speed (between 1800 and 9600 bps) access lines, as well as for the cases where TELPAK rates are either available or unavailable. A cost model was developed to determine overall terrestrial cost for these cases versus the number of nodes per PSN area. Section 7 of this chapter presents this model in greater detail.

3. DEMAND ASSIGNMENT METHODS

a. ALOHA. During the course of this study, a number of satellite broadcast/demand assignment techniques were reviewed for applicability to the 1990 IAS. Many of the approaches were based on the ALOHA system, wherein individual users transmit short messages at random and retransmit them if a conflict occurs. Two major disadvantages of this approach make it unsuitable for the IAS: ALOHA has

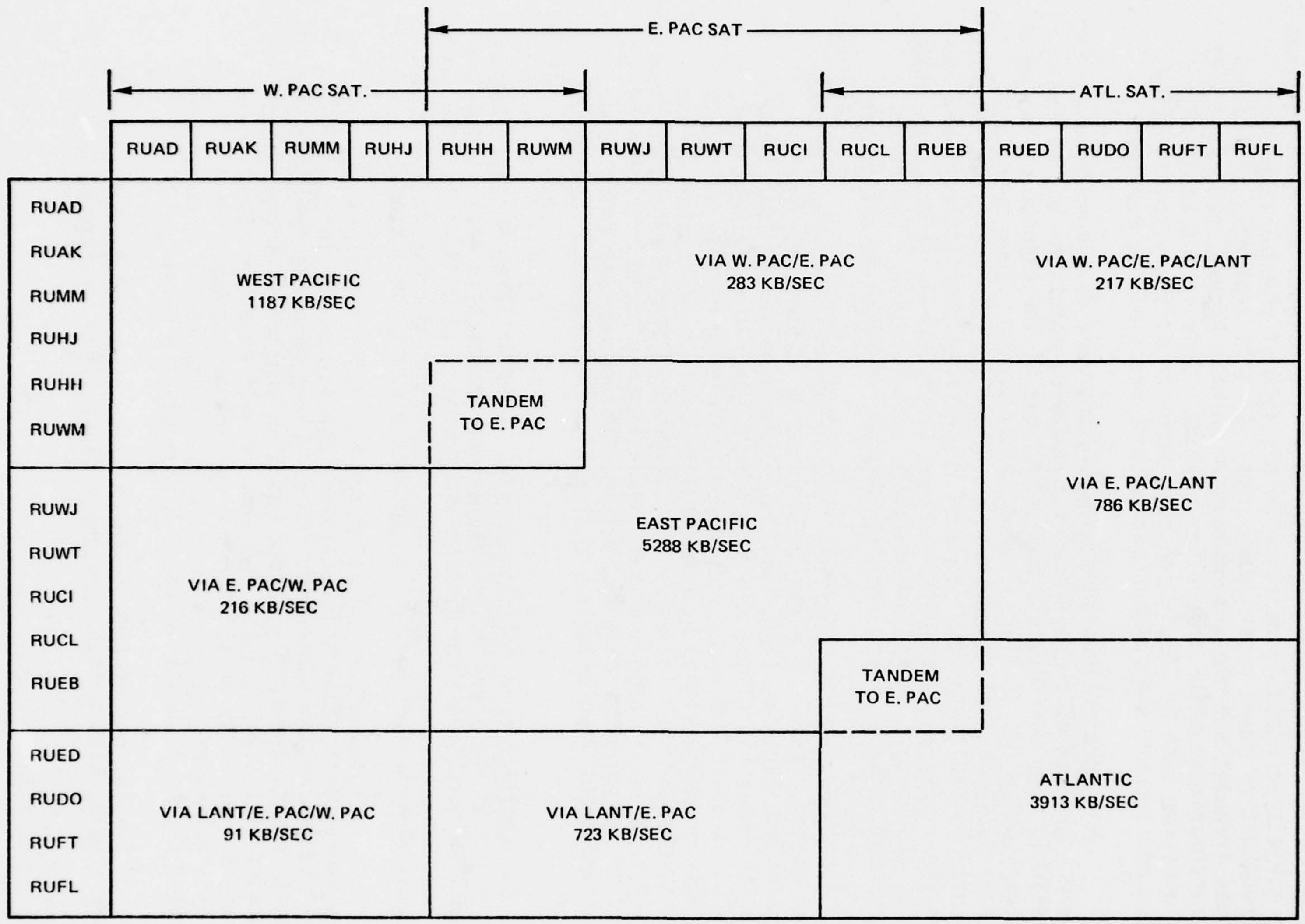


Figure 5. IAS Traffic by Satellite Coverage Area

a low throughput capability (18% of total channel capacity), and therefore is wasteful of expensive satellite assets; and ALOHA systems are subject to unstable behavior in the form of channel saturation (throughput of zero) under heavy load. In this instance, collisions become frequent and the entire channel quickly becomes saturated with retransmissions, which themselves collide. This is not acceptable for a system such as IAS, which must serve in military crisis situations and support the command and control needs of the services.

Most other techniques investigated were developed to overcome one or both of these drawbacks; however, solutions become increasingly more complicated, and often come at the expense of increased delivery delay for traffic offered to the system. Some techniques, such as Split Channel Reservation and CPODA (Contention-based Priority Oriented Demand Assignment) apparently overcome both limitations; however, they rely on a contention scheme for reserving information slots making the request channel susceptible to saturation. Two other approaches, however, are promising and bear further investigation.

b. Round Robin Reservation. The Round Robin Reservation technique uses a fixed TDMA burst structure with dynamic assignment, wherein each earth station "owns" one time slot in the TDMA frame, with the remainder of the slots forming a general assignment pool. Time slots which are owned but unused are also generally available but must be relinquished upon generation of a conflict when access is attempted by the slot owner. Furthermore, Round Robin Reservation uses a priority technique whereby short message packets are queued ahead of long message packets, keeping average message delay below two round trips (approximately 0.5 sec) while throughput approaches unity.

c. Conflict-Free Multiple Access. Conflict-Free Multiple Access is similar to the Round Robin Reservation approach in that it uses a fixed TDMA structure with dynamic assignment. It differs in that, as the name suggests, conflicts in the reservation process do not occur. CFMA divides the TDMA frame into three subframes (or vectors).

The reservation (or R) vector has dedicated slots for each user, where users reserve information capacity in the information (or I) vector of the subsequent frame. Where requests for the same capacity exist, they are resolved based on a priority scheme which allocates each user at least one slot as well as other slots which satisfy the priority relationship. The acknowledgement (or A) vector, contains acknowledgements as to previous transmissions of information accoding to the requests in the R vector and the priority rules.

Simulations of this approach have shown the channel to be highly stable, with a high throughput capability. One possible

drawback, however, lies in the use of the priority scheme for allocating capacity in the I vector whereby excess capacity may not be evenly allocated resulting in a blocking effect. A dynamic priority scheme based on the traffic of other users is one approach to minimizing this effect. Table VIII presents an overview of the demand assignment approaches reviewed and is based primarily on information contained in a Naval Research Laboratory (NRL) Study [5].

It should be mentioned at this point that these DAMA schemes are designed for data transmission only, where the integrity of the data stream is of utmost importance and delivery delay constraints are nearly as critical. The characteristics of voice traffic are such that traffic delayed beyond a certain point becomes meaningless (especially in packet voice schemes). In addition, a greater error rate is tolerable, and circuit set-up times are not nearly as critical. The major design goal is to minimize the probability of a call being blocked consistent with system cost. For these reasons, it is unlikely that a single DAMA technique would be acceptable to both voice and data users. Voice/data integration, if otherwise feasible, would then be limited to the sharing of earth station antenna and RF components, with separate modems and DAMA equipment being required at each site.

The cost of implementing DAMA approaches, both from the hardware and software standpoints, was not determined in this study. However, under the assumption that a TDMA multiple access structure is used, it was felt that DAMA could be implemented with an additional minicomputer or microprocessor system, for which $25,000 has been estimated.

4. SPACE SEGMENT REQUIREMENTS

a. Traffic Capacity. The requirements for the satellite space segment are directly related to the amount of traffic which must be accommodated. Figure 5, presented earlier, showed the total traffic load including 100% overhead allowance for each satellite area broken down into intra-area traffic (i.e., within the West Pacific area) and inter-area traffic (via tandem connection to PSNs in other satellite areas). To determine total load on a given satellite, the sum of all tandem traffic originating, terminating or traversing a satellite area must be added to the intra-area traffic. This process results in the traffic loads shown in Table IX.

These loads assume that all intra-area traffic is offered to the satellite; however, a portion of the traffic is between subscribers homed on a common PSN and thus does not traverse the satellite network.

The greater the number of PSN/earth stations the greater will be the proportion of intra-area traffic offered to the satellite. An

TABLE VIII. SATELLITE DEMAND ASSIGNMENT TECHNIQUES

Technique	Max. Thruput	Avg. Delay @ Max. Thruput	Stability	Remarks
TDMA	1	.25 sec	Stable	Pre-assigned, full period channels
SPADE	1	.25 sec	Stable	FDMA technique-voice oriented, circuit switched
ALOHA	.18	Undetermined	Unstable	Contention scheme, no timing required
Slotted ALOHA	.36	30-40 slots	Unstable	Requires timing to establish slots
Slotted ALOHA w/channel control	.33	30-70 slots	Stable	Control procedures do not increase thruput - requires central timing
Robert's Reservation	≈.8	≈10 round trips	Unstable	Suitable for multi-packet messages, requires framing
Split Channel Reservation	→1	.75 sec min.	Unstable Request Channel	Accommodates variable length and multi-packet messages
Reservation ALOHA	→1	4 round trips min. (6 nodes)	Unstable	New stations easily accommodated, requires framing
CPODA	→1	.25-.5 sec min. for reservation request plus transmission delay	Unstable Request Channel	Still under development-designed for multiple traffic types and priorities
Round Robin Reservation	→1	1.5-10 round trips	Stable	Channel queue tables required, framing required
Conflict-free Mult. Access	→1	Undetermined	Stable	Fixed user priority structure can cause blocking

TABLE IX. SATELLITE AREA TRAFFIC LOADING, 1990

TRAFFIC ROUTING	WEST PACIFIC (Kb/sec)	EAST PACIFIC (Kb/sec)	ATLANTIC (Kb/sec)
W.PAC/W.PAC	1187	-	-
E.PAC/E.PAC	-	5288	-
LANT/LANT	-	-	3913
W.PAC/E.PAC	283	283	-
E.PAC/W.PAC	266	266	-
E.PAC/LANT	-	786	786
LANT/E.PAC	-	723	723
W.PAC/E.PAC/LANT	217	217	217
LANT/E.PAC/W.PAC	91	91	91
TOTAL SATELLITE TRAFFIC	2044	7654	5730

algorithm was developed to estimate this effect, using the assumption that 30% of traffic originated in each PSN area (as represented by current AUTODIN switch areas) will be intra-area. As the number of earth stations in each original PSN area increases, a portion of this 30% will become inter-PSN traffic between the smaller PSNs. The total proportion of traffic originated within a satellite coverage area for delivery to other PSNs within the original area can then be expressed as:

$$\rho = \left(1 - \frac{.30}{n}\right)$$

where n is the number of earth stations within each large PSN area.

To this must be added tandem traffic into, out of, and through the satellite area to yield the total satellite traffic load as a function of n. Results of this process are shown for each satellite area and for representative values of n in Table X. Satellites in the West Pacific, East Pacific and Atlantic areas must therefore be able to accommodate total traffic loads of 2, 7 and 5 Mb/sec, respectively.

b. Satellite Parameters. Given the above traffic loads, the satellites used must have sufficient bandwidth to pass the offered traffic. In addition, satellite radiated power must be sufficient to transmit the traffic to earth stations of "reasonable" size.

Required satellite transponder bandwidths can be determined from the relationship:

$$W = R_b - B + C_w$$

where

W = required bandwidth (dB·Hz)

R_b = burst rate (required traffic rate in dB·bps)

B = bit-rate-to-symbol rate ratio

(3 dB assumed, QPSK modulation)

C_w = ratio of W to bandlimited rate

(typically 0.8 dB)

TABLE X. SATELLITE LOADING AS A FUNCTION OF NUMBERS OF EARTH TERMINALS PER PSN AREA

		SATELLITE REGION		
n	ρ	WEST PACIFIC	EAST PACIFIC	ATLANTIC
1	.70	1688 Kb/sec	6068 Kb/sec	4556 Kb/sec
2	.85	1866 Kb/sec	6862 Kb/sec	5143 Kb/sec
4	.93	1961 Kb/sec	7285 Kb/sec	5456 Kb/sec
7	.96	1997 Kb/sec	7443 Kb/sec	5574 Kb/sec
10	.97	2008 Kb/sec	7496 Kb/sec	5613 Kb/sec
20	.99	2032 Kb/sec	7602 Kb/sec	5691 Kb/sec
40	1.0	2044 Kb/sec	7654 Kb/sec	5730 Kb/sec
70	1.0			
100	1.0			

Table XI shows the required transponder bandwidths for burst rates of 2, 5 and 7 Mb/sec and the planned bandwidths of transponders in the DSCS III [6] and INTELSAT V [10] satellites. It can be seen that more than sufficient bandwidth exists to accommodate the projected IAS traffic loads.

Given sufficient bandwidth, satellite power requirements are a function of the burst rate requirement and permissible error rate. Satellite power capabilities are determined early in the design phase, and are steadily increasing to accommodate smaller earth terminals. For DSCS III the assumed transponder EIRPs for channels 3 through 6 (allocated to the DCS) are:

- Channel 3 - 29 dBw
- Channel 4 - 30 dBw
- Channel 5 - 27 dBw
- Channel 6 - 27 dBw.

These represent conservative numbers applicable to all DSCS III satellites. For INTELSAT V, the transponder EIRP was assumed to be 36 dBw, which represents a "de-focusing" of the 41 dBw spot beam to hemispheric coverage.

Satellite receive system parameters are also determined early in the design phase. For DSCS III, a G/T figure of -15 dB/°K was assumed, which reflects the capability of the satellite using the earth coverage horn antenna. For INTELSAT V, a G/T figure of -5 dB/°K was used, representing a de-focusing of the 0 dB/°K 14 GHz East spot beam.

5. GROUND SEGMENT REQUIREMENTS

a. Capacity Requirements. The required capacity of an earth station is only one part of the overall satellite system equation, and depends not only on the performance of the space segment, but on the overall system configuration. The impact of multiple access techniques is extremely important in this regard. Frequency division multiple access (FDMA) allows each earth station to be sized according to its individual traffic load and the data rates of signals to be received. In practice, however, this has resulted in standardized earth station sizes, enabling individual links to be reconfigured with minimum hardware impact. Moreover, FDMA requires a large investment in downconverters in a multi-station network in order to provide full connentivity, and thus is not well suited to a broadcast oreinted system.

Time division multiple access, on the other hand, is much better suited for broadcast operation since all stations share a common frequency in the time domain, so only a single RF channel is required. This, however, comes at the expense of increased data rate

TABLE XI. SATELLITE TRANSPONDER BANDWIDTH REQUIREMENTS AND CAPABILITIES

REQUIREMENT/CAPABILITY	TRANSPONDER BANDWIDTH
WEST PACIFIC REQUIREMENT - 2MB/SEC	1.2 MHz
EAST PACIFIC REQUIREMENT - 7MB/SEC	3.0 MHz
ATLANTIC REQUIREMENT - 5MB/SEC	4.2 MHz
DSCS III SATELLITE - CH.3	85 MHz
CH.4	60 MHz
CH.5	60 MHz
CH.6	50 MHz
INTELSAT V SATELLITE - 14/11 GHz	72 MHz

requirements for each earth station and can lead to frequency coordination problems where frequencies are shared with terrestrial systems. In a TDMA broadcast network, each station must be able to receive all network traffic at the network burst rate, selecting only that traffic destined for subscribers that it serves. Thus an earth terminal with a throughput requirement of only 100 Kb/sec may be required to operate at a burst rate of 5 Mb/sec if that is the overall satellite traffic load.

Because all broadcast techniques considered in this study operate in the time domain, satellite and earth station burst rates are the same and earth station capacities equate to the satellite capacities discussed in the previous section in each satellite coverage area (i.e., 2 Mb/sec in the West Pacific, 7 Mb/sec in the East Pacific, and 5 Mb/sec in the Atlantic area).

b. Performance Requirements. Given satellite EIRP figures and system burst rates, it is possible to determine the performance requirements of the ground segment. For the downlink (satellite to earth) the figure of merit (G/T) is important. This may be determined from the following link power budget relationship:

$$\text{Required } G/T = R_b - EIRP_{sat} + L_s + k + (E_b/N_o)_d + M$$

where:

R_b = system burst rate (dBHz)

$EIRP_{sat}$ = Satellite effective radiated power (dBw)

L_s = free space loss over the space-to-earth path

k = Boltzmann's Constant (-228.6 dBw/H_z°K)

$(E_b/N_o)_d$ = required bit energy to noise density ratio on the downlink for a given bit error rate (9.6 dB for 10^{-5} BER, QPSK modulation)

M = link margin (typically 6 dB).

If the transponder power is shared proportionate to occupied bandwidth, the formula becomes:

$$G/T = R_b - EIRP_{channel} + L_s + k + (E_b/N_o)_d + M + P_{bo}$$

$$= R_b - (EIRP_{sat} + R_b - B + C_w - W) + L_s + k + (E_b/N_o)_d + M + P_{bo}$$

where P_{bo} represents the transponder power backoff (normally 3 dB) required for multiple carrier operation, and the term $R_b - B + C_w$ represents the required bandwidth for a burst rate R_b. The term within parenthesis, therefore, represents the proportionate allocation of transponder EIRP. Collecting terms, the formula becomes:

$$G/T = B + W - C_w - EIRP_{sat} + L_s + k + (E_b/N_o)_d + M + P_{bo}.$$

Thus, when a transponder is shared on a proportionate power basis, the required terminal G/T is independent of the burst rate and a single "standard" size terminal is dictated.

For the systems under consideration here, the required earth station G/T figures are presented in Table XII.

To achieve a given G/T, a combination of antenna size (and hence gain) and receiver low-noise amplifier (LNA) must be selected which meets the requirement at minimum cost. Using data previously prepared [2], the least cost combination was determined for each system burst rate and is also presented in Table XII.

For the up-link (ground to space) a similar power budget relationship holds. Given the satellite receive G/T and earth station antenna gain, the required uplink transmitter power can be determined by the relationship:

$$P_T = R_b - G/T_{sat} + L_s + k + (E_b/N_o)_u + M - G_{ES}$$

where the terms are as previously defined for the downlink except:

$(E_b/N_o)_u = (E_b/N_o)_d + 6$ dB (to ensure a downlink limited system)

G_{ES} = earth station antenna gain as determined by downlink criteria.

For the burst rates and system being considered, the required transmitter high power amplifier (HPA) outputs are shown in Table XIII.

While the antenna, LNA and HPA are the major cost items and perform the prime functions of transmission and reception, an earth station obviously requires more. "Common equipment" required includes up and down converters, IF subsystems, modems, equipment racks, frequency standards and other items, as well as test equipment, documentation, spares and the like. These items will be considered further in the discussion of earth station cost in the following section.

TABLE XII. EARTH STATION RECEIVE SYSTEM PARAMETERS

	DSCS III				INTELSAT V			
DEDICATED TRANSPONDER	G/T (dB/°K)	Ant. Dia. (Feet)	Ant. Gain (dB)	LNA (°K)	G/T (dB/°K)	Ant. Dia. (Feet)	Ant. Gain (dB)	LNA (°K)
2 Mb/sec	25	15	49	200	18.5	6	45.9	300
5 Mb/sec	29	20	51.5	150	22.5	8	48.4	300
7 Mb/sec	30.5	20	51.5	100	24.0	10	50.3	300
Shared Transponder, All Rates	44.5	60	61	45	39.3	30	59.8	110

Note: DSCS III: EIRP = 27 dBw, (dedicated 60 MHz transponder)
= 29 dBw (shared 85 MHz transponder)
L_S = 202 dB

INTELSAT V: EIRP = 36 dBw,
L_S = 204.5 dB

TABLE XIII. EARTH STATION HPA REQUIREMENTS

BURST RATE	HPA POWER (dBw)	
	DSCS III	INTELSAT V
Dedicated Transponder		
2 Mb/sec	24.0	19.6
5 Mb/sec	25.5	21.1
7 Mb/sec	27.0	20.7
Shared Transponder*		
2 Mb/sec	6.0	-.3
5 Mb/sec	10.0	3.7
7 Mb/sec	11.5	5.2

* Includes 6 dB backoff required to prevent transponder saturation in multiple carrier operation.

6. SATELLITE SYSTEM COST ESTIMATION

a. General. With the basic system capacity and performance parameters established, attention can now be turned to the estimation of system cost, which can be broken down between the space segment and the ground segment.

b. Space Segment. The cost of producing and orbiting a communications satellite is not easily determined a priori. However, work has been done on developing cost estimating relationships (CERs) for determining approximate figures [7]. These relationships were found to be primarily dependent on the payload weight and complexity and orbital altitude. A formula was developed relating these as follows:

For a single satellite in a circular orbit:

$$C_S = .026\ (W_S)^{2/3}\ (1 + K + \frac{H}{8000})$$

where

C_S = Cost of payload and launch

W_S = Weight of satellite (lb.)

H = Height of orbit (mi.)

K = Factor related to satellite complexity

For a launch of n satellites in one ring:

$$C_S = .026\ (n\ W_S)^{2/3}\ (1 + K + \frac{H}{8000})$$

For DSCS III, two satellites weighing 1600 lbs. each are launched at one time. For INTELSAT V, a single satellite of 4100 lbs. is launched at a time. A "K" value of 4 was assumed based on emperical relationships for satellites of similar complexity [7]. The resulting "costs to orbit" and cost per transponder are presented in Table XIV. Also presented in the table are the cost estimates for INTELSAT V and DSCS III using the space shuttle instead of an expendable launch vehicle.

c. Ground Segment. The costs of earth stations are in large part determined by the required station capacity. This, in turn, can be divided into receive subsystem, transmit subsystem, and common equipment categories. Based on the figures of previous sections, and cost curves contained in [2], earth station equipment costs were estimated and are shown in Table XV, which represent single item costs.

TABLE XIV. ESTIMATED SATELLITE COSTS, LAUNCHED 1977 DOLLARS

	DSCS III		INTELSAT V	
	EXPENDABLE LAUNCH VEH	SHUTTLE LAUNCH	EXPENDABLE LAUNCH VEH	SHUTTLE LAUNCH
NUMBER OF SATS PER LAUNCH	2		1	
SATELLITE WT. (LBS)	1600		4100	
TOTAL SAT. BANDWIDTH (MHz)	375		2137	
TRANSPONDER BANDWIDTH (MHz)	60		72	
TOTAL COST PER SAT, LAUNCHED	$ 22.0 M	$ 16.0 M	$ 52.0 M	$ 26.0 M
COST FOR ONE TRANSPONDER	$ 3.5 M	$ 2.6 M	$ 1.75M	$876 K
COST FOR PARTIAL TRANSPONDER*				
2 MB/SEC	$ 70 K	$ 51 K	$ 29 K	$ 15 K
5 MB/SEC	$176 K	$128 K	$ 73 K	$ 36 K
7 MB/SEC	$246 K	$179 K	$102 K	$ 51 K

* OCCUPIED BANDWIDTHS FOR 2.5 AND 7.0 Mb/sec BURST RATES USING QPSK MODULATION ARE 1.2, 3.0 AND 4.2 MHz RESPECTIVELY.

TABLE XV. EARTH STATION EQUIPMENT COST ESTIMATE (1977 DOLLARS)

SYSTEM PARAMATERS			ANTENNA +LNA	HPA	TDMA EQPT	DEMAND ASSIGNMENT EQUIPMENT	TOTAL EQUIPMENT COST
DSCS III	DEDICATED TRANS-PONDER	2 MB/s	$ 30K	$35K	$50K	$25K	$140K
		5 MB/s	$ 53K	$42K	$50K	$25K	$170K
		7 MB/s	$ 65K	$53K	$50K	$25K	$193K
	SHARED TRANS-PONDER	2 MB/s	$800K	$ 6K	$50K	$25K	$881K
		5 MB/s	$800K	$ 7K	$50K	$25K	$882K
		7 MB/s	$800K	$ 8K	$50K	$25K	$883K
INTELSAT V	DEDICATED TRANS-PONDER	2 MB/s	$ 16K	$27K	$50K	$25K	$118K
		5 MB/s	$ 18K	$35K	$50K	$25K	$128K
		7 MB/s	$ 20K	$33K	$50K	$25K	$128K
	SHARED TRANS-PONDER	2 MB/s	$120K	$ 4K	$50K	$25K	$199K
		5 MB/s	$120K	$ 5K	$50K	$25K	$200K
		7 MB/s	$120K	$ 6K	$50K	$25K	$201K

Where n identical earth terminals are purchased, the equipment cost per terminal (C_T) is related to the single item cost (C_1). by the relationship:

$$C_T = C_1 \, Y^{\log_2 n}$$

where Y is a discount factor (nominally assumed to be .95).

The equipment cost per earth terminal thus determined provides the basis for determining the additional costs required to place each earth terminal in operation, which includes test and support equipment, documentation, spares, transportation and the like. In [2] it was estimated that these costs (exclusive of documentation) would equal $2.391C_T$. Documentation costs were assessed at 2.5 C_1. Therefore, a total system of n identical terminals would cost:

$$C_N = n(C_T + 2.391\ C_T) + 2.5\ C_1$$

or

$$C_N = 3.391\ n\ C_1\ (.95)^{\log_2 n} + 2.5\ C_1$$

$$C_N = [3.391_n (.95)^{\log_2 n} + 2.5]\ C_1$$

$$C_N = F(n)\ C_1$$

The multiplying factor F(n) has been determined for a range of values of n (selected to facilitate plotting) and has been applied to the individual earth station equipment cost figures from Table XV to yield the total satellite ground segment costs shown in Table XVI.

d. Total System Cost. Knowing the costs of the space segment (satellite transponder and launch costs) and the ground segment (earth terminal equipment and activation cost), the total system cost is merely the sum of these two. Adding the costs for space and earth segments presented in Tables XIV and XVI yields total estimated system cost in 1977 dollars. Two adjustments must be made, however, to enable comparisons to terrestrial systems costs in the 1990 time frame. The first is to scale total system costs upward to account for inflation. A six percent annual inflation rate will result in an overall doubling of system dollar costs by 1990. The second adjustment to be made is to express total system costs on an annual basis to enable comparison with leased services.

TABLE XVI. TOTAL EARTH SEGMENT COST FOR TERMINALS (1977 DOLLARS)

		DSCS III				INTELSAT V		
		DEDICATED TRANSPONDER			SHARED XPNDR	DEDICATED XPNDR		SHARED XPNDR
No. of Earth Stations	F(n)	2 Mb/s	5Mb/s	7 Mb/s	All Rates	2 Mb/s	587 Mb/s	All Rates
15	44.1	$ 6.2M	$ 7.5M	$ 8.5M	$38.9M	$ 5.2M	$ 5.6M	$ 8.8M
30	81.6	$11.4M	$13.9M	$15.7M	$72.0M	$ 9.6M	$10.4M	$16.3M
60	153	$21.4M	$26.0M	$29.5M	$135M	$18.1M	$19.6M	$30.6M
100	244	$34.2M	$41.5M	$47.1M	$215M	$28.8M	$31.2M	$48.8M
150	354	$49.6M	$60.2M	$68.3M	$312M	$41.8M	$45.3M	$70.8M
300	670	$93.8M	$114M	$129M	$591M	$79.1M	$85.8M	$134M
600	1270	$178M	$216M	$245M	$1120M	$150M	$163M	$254M

Annual costs (C_A) can be determined from the relationship:

$$C_A = \frac{C_T}{k}$$

where C_T is the total system cost and k is a "Capital Recovery Factor" dependent on the expected life of the assets and on assumed discount rate (if a ten-year life and a discount rate of 8-3/4 percent is assumed, the resulting value of k is 6.45).

Table XVII presents total and annual satellite systems costs for 1990 reflecting these two adjustments.

d. O&M Manpower Costs. A major cost factor in a satellite communication system is the manpower required to operate and maintain the system. DCA Circular 600-60-1 specifies a manning level of 20 for each earth station (three shifts of four men, plus one team on training and one reserve). This amount is felt to be excessive considering the current and projected state-of-the-art for small earth stations. For this analysis, however, manning levels ranging from zero (unattended) to the currently stipulated twenty will be used for costing purposes.

Based on data contained in [2] the average cost per man-year is currently $45.7 K, and by 1990 is expected to double to approximately $90K. Total system manloading costs for a range of earth terminal quantities are shown in Table XVIII. It can be seen that manpower costs quickly overshadow annual equipment costs as manloading increases.

e. Annual System and Operating Costs. Figure 6 presents the data from Tables XVII and XVIII in graphic form, showing 1990 annual system cost as a function of earth terminals, satellite used, terminal capacity and manloading.

7. TERRESTRIAL SYSTEM COST ESTIMATION

a. General. Having established basic assumptions regarding the terrestrial network (Chapters I and IV), the cost of a terrestrial transmission system for the 1990 IAS can be developed. This system divides logically into a backbone portion (connecting PSNs) and an access portion (connecting subscribers to the PSNs).

b. Backbone Cost. At present tariffs for 2400 bps and 4800 bps circuits, the current AUTODIN backbone costs approximately $2 million annually. It is expected that this figure will be modified by three factors by 1990. First, the number of links is expected to be reduced to 34 from the present 40, reflecting a reduction in the number of switch node locations from 17 to 15. Secondly, the speed of each backbone circuit is expected to increase to 56 kbps. With the present

TABLE XVII. SATELLITE SYSTEM COST (1990 DOLLARS, SHUTTLE LAUNCH)

Number of Earth Stations	DSCS III (3 Satellites)								INTELSAT V (3 Satellites)					
	DEDICATED TRANSPONDERS						SHARPENED TRANSPONDERS		DEDICATED TRANSPONDERS				SHARPENED TRANSPONDERS	
	2 Mb/Sec		5 Mb/Sec		7 Mb/Sec		ALL RATES		2Mb/Sec		5&7 Mb/Sec		ALL RATES	
	TOT. $M	ANN. $M	TOT. $M	ANN. $M	TOT. $M	ANN. $M	TOT. $M	ANN. $M	TOT. $M	ANN. $M	TOT. $M	ANN. $M	TOT. $M	ANN $M
15	28.0	4.3	30.6	4.7	32.6	5.1	78.6	12.2	15.7	2.4	16.4	2.5	17.8	2.8
30	38.4	6.0	43.4	6.7	47.0	7.3	145	22.5	24.5	3.8	26.1	4.0	32.8	5.1
60	58.4	9.1	67.6	10.5	74.6	11.6	271	42.0	41.5	6.4	44.5	6.9	61.4	9.5
100	84.0	13.0	98.6	15.3	110	17.1	431	66.8	62.9	9.8	67.7	10.5	97.8	15.2
150	115	17.8	136	21.1	152	23.6	625	96.9	88.9	13.8	95.9	14.9	142	22.0
300	203	31.5	244	37.8	274	42.5	1183	183	163	25.3	177	27.4	268	41.6
600	372	57.7	448	69.5	506	78.4	2241	347	305	47.3	331	51.3	508	78.8

TABLE XVIII. MANNING LEVEL COSTS

n EARTH TERMINALS	ANNUAL MANNING COST ($M, 1990)			
	4 MY	8 MY	12 MY	20 MY
15	5.4	10.8	16.2	27
30	10.8	21.6	32.4	54
60	21.6	43.2	64.8	108
100	36	72	108	180
150	54	108	162	270
300	108	216	324	540
600	216	422	648	1080

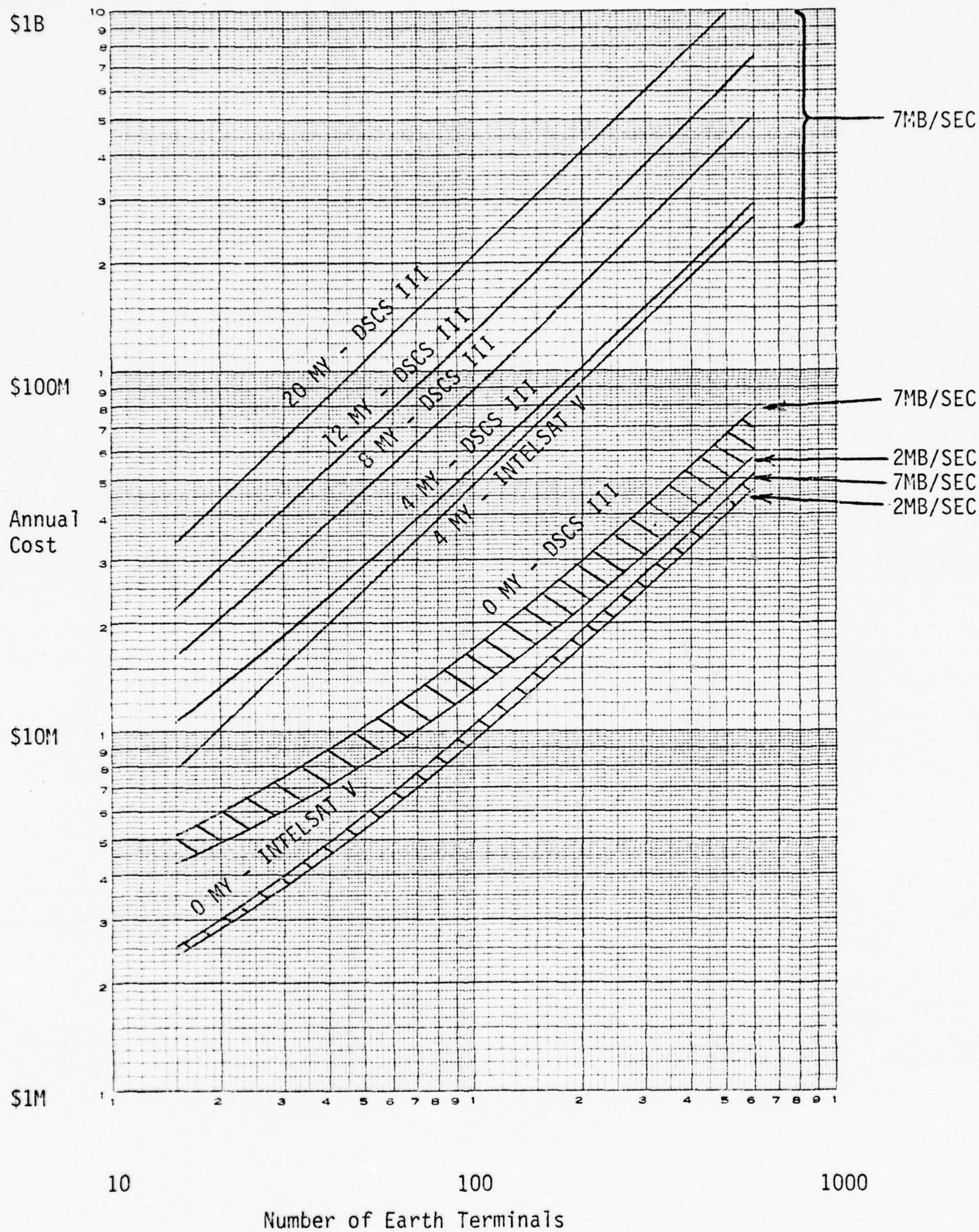


Figure 6. Satellite System Annual Cost, 1990

tariff structure, this means going from TELPAK rates to Series 8000 (wideband) rates. On the average, this can be expected to increase costs by 2.5 times. Finally, the effects of inflation (assumed to average 6%) will result in an additional doubling of costs. For 1990 then, a terrestrial IAS backbone is estimated to cost:

$$\$2M \times \frac{34}{40} \times 2.5 \times 2 = \$8.5M$$

This figure may be reduced due to technological breakthroughs or the installation of extensive digital plant, however, it was beyond the scope of this study to project these effects.

c. Access Cost. Given the current AUTODIN subscriber access cost of $14 million annually and a projected growth in subscribers from the present 1500 to approximately 4000 in 1990 (Table II), total access costs can be expected to increase to approximately $37M. This figure is rather pessimistic in that new technologies (i.e., fiber optics) may reduce these costs. A factor of two is again needed to represent inflation to 1990. The resulting annual cost of $74 million represents the 1990 terrestrial transmission costs assuming no increase in line speeds or tariffs.

Because the requirements for higher speed service are expected to continue to increase, a greater proportion of users will increase their access line speeds to take advantage of new service offerings (e.g., interactive data transfer, high speed facsimile, etc.). This increase will cause access costs to further increase. It is projected that costs for higher speed access lines will average 1.5 times that at present, based on present TELPAK equivalent-bandwidth tariff structures. However, as discussed earlier in this report, the possibility that TELPAK rates may be abolished is very real. Cost estimates by government agencies estimate that the elimination of TELPAK will increase costs between 30% and 45%. Figure 7 illustrates the expected annual cost for an all-terrestrial IAS transmission network, showing the effects of access line speed mix and the possible elimination of the TELPAK tariff. For a TELPAK based system with all subscribers operating at less than 1800 bps, access costs are estimated to total $74 million in 1990. The worst case estimate is $161 million, reflecting MPL rates (i.e., no TELPAK) and 100% high speed access.

d. Effects of Satellite Service on Access Cost. In order to determine the variation in terrestrial access costs as the number of satellite earth stations is increased, a simplified model was developed which assumes that subscribers are evenly distributed throughout each PSN area. As the PSN area is subdivided into N sections (each representing an earth station location) the number of subscribers served in each section is proportional to 1/N. At the same time, since the area of each section is proportional to 1/N, the length of each access line

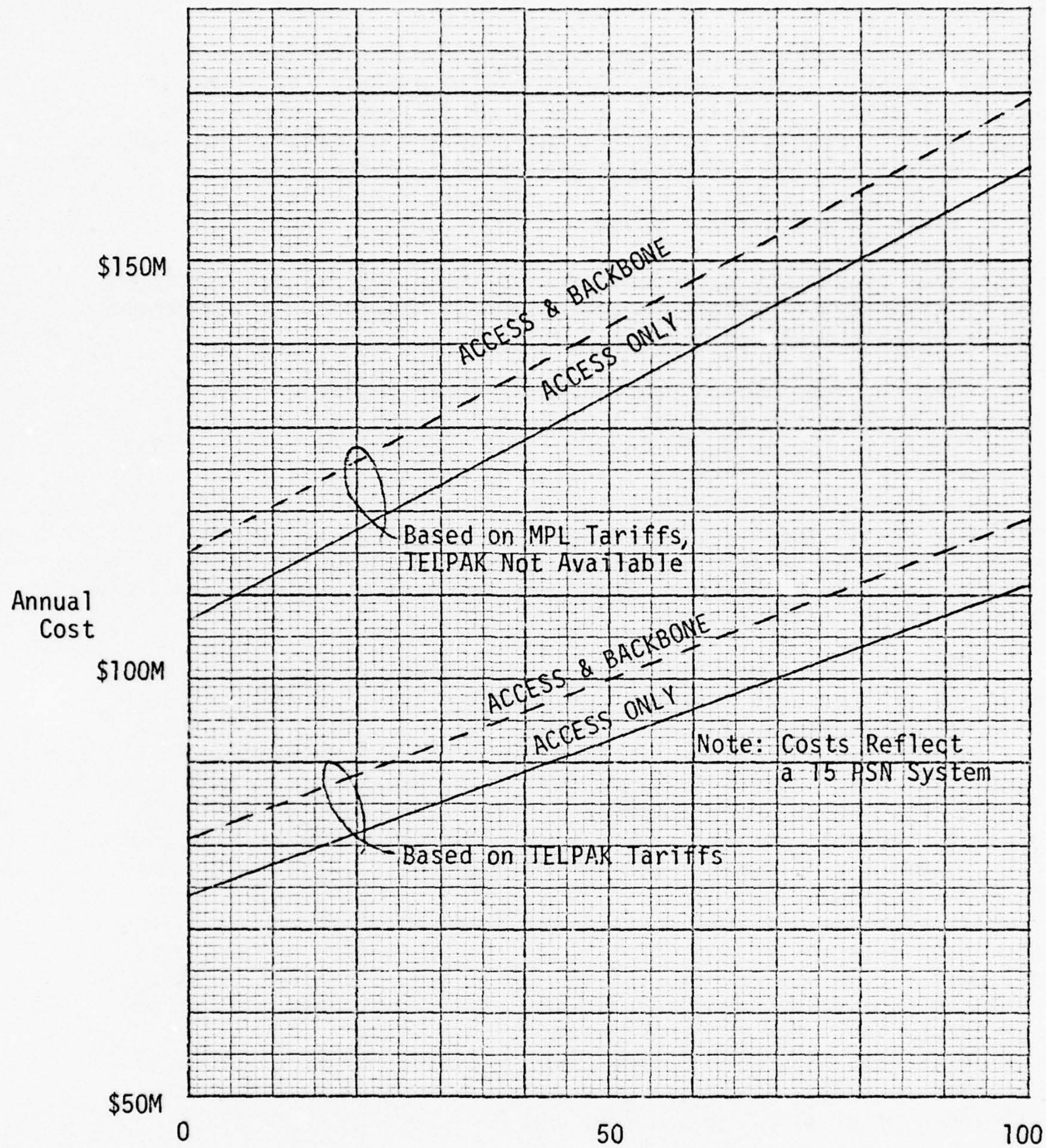


Figure 7. Terrestrial System Annual Cost, 1990

in the section is proportional to $1/\sqrt{N}$. Thus for each smaller section, the total access line length is $1/N(1/\sqrt{N})$, and for the original PSN area (N sections) the average line length (and hence access cost) has been reduced by $1/\sqrt{N}$.

Table XIX shows total terrestrial costs expected to result from this subdivision, both for a worst case situation and for a low speed TELPAK case.

8. TOTAL SYSTEM ESTIMATES

The above terrestrial transmission costs were added to the total satellite system costs determined earlier to yield the estimated IAS annual transmission costs for 1990, which are shown in Table XX and plotted in Figures 8 and 9, reflecting both least cost and maximum terrestrial rate structures.

It can be seen that satellite transmission can achieve substantial cost reductions, but these are quite sensitive to manpower costs. For minimally manned (but not unattended) earth station (four man years per year), savings of between \$11 million and \$55 million can be expected in 1990 over the cost of an all-terrestrial transmission system. These savings occur within a range of 30-90 earth terminals worldwide, which translates to two to six satellite nodes per original PSN area. Future architectural alternatives for the IAS should, therefore, consider a system utilizing a larger number of smaller switch nodes with co-located earth terminals to take advantage of potential satellite savings.

TABLE XIX. TERRESTRIAL COSTS VERSUS NUMBER OF EARTH STATIONS PER PSN AREA

SAT. TERMS PER PSN AREA N	TERRESTRIAL ACCESS COST RATIO $\left(\frac{1}{\sqrt{N}}\right)$	ANNUAL TERRESTRIAL COST (1990 DOLLARS)	
		MINIMUM (TELPAK, LOW SPEED)	MAXIMUM (MPL, HIGH SPEED)
0	-	\$82.0 M	\$169 M
1	1	\$74.0 M	\$161 M
2	.71	\$52.5 M	\$114 M
4	.50	\$37.0 M	\$ 80.5 M
6.67*	.39	\$28.9 M	\$ 62.8 M
10	.32	\$23.7 M	\$ 51.5 M
20	.22	\$16.3 M	\$ 35.4 M
40	.16	\$11.8 M	\$ 25.8 M

* TRANSLATES TO 100 TERMINALS WORLDWIDE

TABLE XX. ANNUAL SYSTEM COST, SATELLITE AND TERRESTRIAL, 1990 ($M)

Total Sat. Earth Stns.	Earth Stns. Per PSN Area	TELPAK, Low Speed Access						MPL, High Speed Access					
		INTELSAT V	DSCS III					INTELSAT V	DSCS III				
		0 MY	0 MY	4 MY	8 MY	12 MY	20 MY	0 MY	0 MY	4 MY	8 MY	12 MY	20 MY
0	0	82	82	82	82	82	82	169	169	169	169	169	169
15	1	76.5	79.1	84.5	89.9	95.3	106	164	166	171	177	182	193
30	2	56.5	59.8	70.6	81.4	92.2	114	118	121	132	143	153	175
60	4	43.9	48.6	70.2	91.8	113	157	87.4	92.1	114	135	157	200
100	6.67	39.4	46.0	82.0	118	154	226	73.3	79.9	116	152	188	260
150	10	38.6	47.3	101	155	209	317	66.4	75.1	129	183	237	345
300	20	43.7	58.8	167	275	383	599	62.8	77.9	186	294	402	618
600	40	63.1	90.2	306	512	738	1170	77.1	104	320	526	752	1184

Assumes: 7MB/Sec. Satellite System
Dedicated Transponders
Shuttle Launch

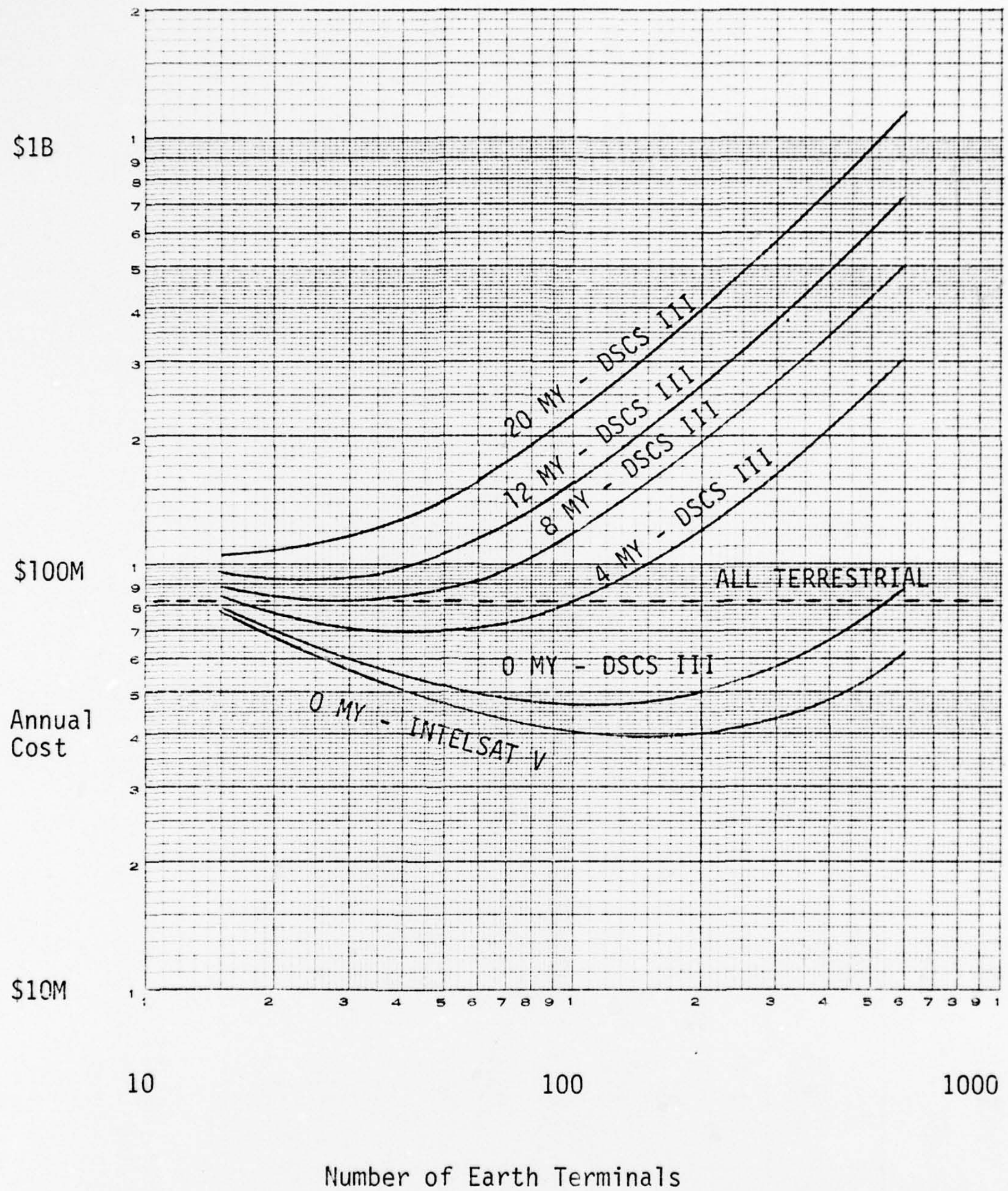


Figure 8. Total Annual Cost, Satellite and Terrestrial, TELPAK Rates, Low Speed Access

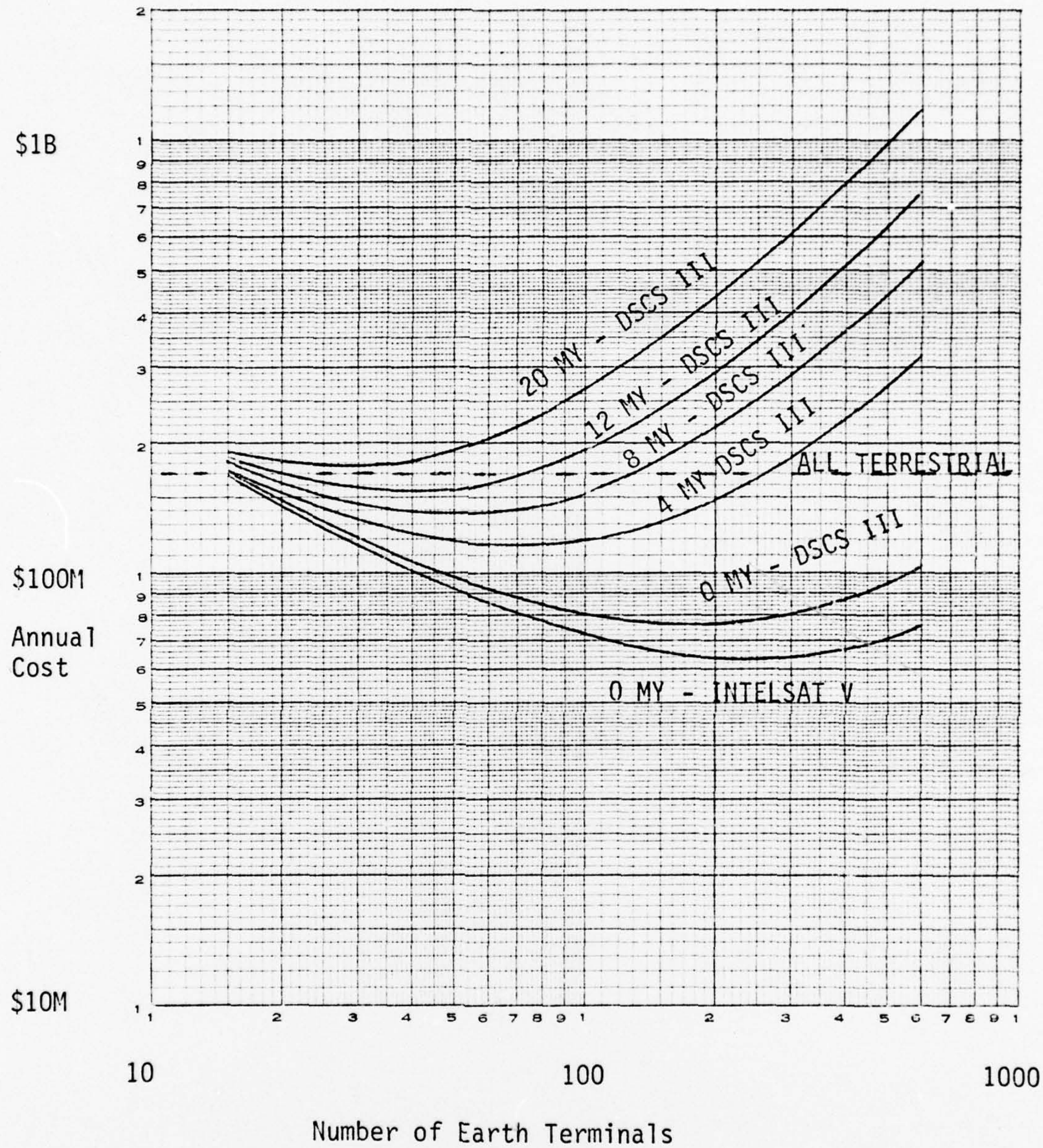


Figure 9. Total Annual System Cost, Satellite and Terrestrial, MPL Rates, High Speed Access

VII. A STRAWMAN 1990 IAS SATELLITE IMPLEMENTATION

VII. A STRAWMAN 1990 IAS SATELLITE IMPLEMENTATION

1. GENERAL

The preceeding analyses used a parmetric approach to show the cost sensitivities of satellite system elements to the total number of earth stations employed, and are therefore useful in system planning. They do not, however, bring all the elements together where interrelationships and tradeoffs can be seen in a system context. The purpose of this chapter, then, is to present a "strawman" implementation of a cira 1990 IAS satellite system. It should be stressed that this is not a recommended system, but is only one of a number of possible system configurations. Further definition of the IAS architecture will be required before system recommendations can be made.

2. SYSTEM OVERVIEW

The strawman 1990 IAS satellite system is based upon the projected traffic loads of Chapter III. The basic assumptions adopted for the configuration of the strawman system are as follows:

- DSCS III satellite, Space Shuttle launch
- TDMA system with 7 Mb/sec burst rate
- Dedicated transponder on each satellite
- Sixty earth stations worldwide (four per present ASC region)
- Round Robin Reservation DAMA approach
- No TELPAK tariff available
- Fifty percent of access lines operating at greater than 1800 bps.

The system resulting from the adoption of these assumptions and its pros and cons are described in the following paragraphs.

3. SPACE SEGMENT

a. Description. The space segment for the strawman 1990 IAS satellite system consists of DSCS III satellites launched via Space Shuttle and expendable orbit insertion vehicles. A single transponder on each satellite is dedicated to IAS use, with a transponder

power output of 27 dBw using earth coverage horn antennas for transmit and receive. Total per-transponder cost, including the proportionate share of launch costs, is estimated at 2.6 million dollars (1977 cost) or 5.2 million dollars in 1990. For three transponders (West Pacific, East Pacific, and Atlantic Satellites), the total 1990 space segment cost is therefore 15.6 million dollars.

b. Discussion. The decision to provide a dedicated transponder for IAS use is based on the need to keep earth terminals down to a "reasonable" size consistent with a TDMA multiple access format. The entire 27 dBw of transponder is available to support the 7 Mb/sec burst rate required. If, on the other hand, the transponder was shared with other users in proportion to occupied bandwidth, only 12.5 dBw would be available to IAS users. This is a result not only of the use of only seven percent of transponder bandwidth (4.2 MHz out of a total 60 MHz), but an additional 3 dB penalty because of transponder "back-off" necessary to prevent severe intermodulation noise in multi-carrier service. This will severely impact earth station requirements as will be discussed in the following section.

If FDMA were used, each earth station would only have to support the data rate required for its own traffic. However, FDMA is not a "broadcast" technique, but is more suited to point-to-point circuits. For this reason, it was not considered in detail in this study.

Dedicated use of a single 60 MHz transponder for 7 Mb/sec of traffic seriously affects the overall efficiency of the space segment. Such an arrangement presupposes the resolution of the large number of conflicting requirements for DCS satellite assets. With four transponders of each DSCS III satellite earmarked for DCS use, it is assumed that the critical role played by the IAS will be sufficient justification for a dedicated transponder.

The use of the Space Shuttle to launch the satellite is based on the economics that this method is expected to provide by 1990. If shuttle launch is not feasible, space segments costs for a dedicated transponder can be expected to increase to 3.5 million dollars in 1990.

4. EARTH SEGMENT

a. Description. The strawman 1990 IAS earth segment is comprised of 60 earth terminals using 20-foot (6-meter) diameter antennas and $100^{\circ}K$ low noise amplifiers, resulting in a figure-of-merit (G/T) of 30.5 $dB/^{\circ}K$. The earth station HPA will operate at a power of 27 dBw, sufficient to insure a down-link limited system.

Operation will be TDMA at a burst rate of 7 Mb/sec using Round Robin Reservation as the broadcast protocol. Total earth segment cost including equipment and installation is expected to be 53.6 million dollars in 1990. Each earth station will be manned at a level of four man years per year (one-man operation for three shifts, one shift on vacation or training). The total annual manpower cost (240 man years) is expected to reach 21.6 million dollars by 1990.

b. Discussion. The figure of 60 earth terminals represents four earth terminals in each of fifteen "PSN areas" as defined by current AUTODIN I ASC service areas. It was felt that this number represents a compromise between satellite system cost savings and the cost of additional switching facilities. Although this study assumed all switching nodes were in place for analysis purposes, it is recognized that, as the number of nodes increases, switching subsystems costs can rise drastically. For this reason, it was felt the four switches for each current switch was a reasonable limit (resulting in an average of 65 subscribers per switch).

Earth terminals were sized in accordance with the data developed in Chapter VI for 7 Mb/sec TDMA. Although some service regions may not present the full 7 Mb/sec of traffic, this figure was used worldwide in the interest of commonality, and to provide for growth, especially in the West Pacific and European regions.

TDMA operation was chosen because of the need for "broadcast" type operation. As discussed previously, this assumes the availability of an entire satellite transponder. If available down-link power were reduced in proportion to occupied bandwidth (and including the transponder power back-off necessary for multiple carrier operation) earth station requirements would change drastically. With an available satellite EIRP of 12.5 dBw, required earth station G/T for 7 Mb/sec TDMA would be 44.5 dB/°K (Table XII). This would result in prohibitively large earth staions, which would not be economical for the small amount of traffic to be carried. If FDMA were used, smaller earth stations could be used (capacity approximately 500 kb/sec each), but broadcast operation could not be provided.

The Round Robin Reservation scheme was chosen because of its promise in providing true broadcast demand assignment service while at the same time providing channel stability under periods of heavy load and avoiding excessive transmission delay. It should be emphasized that this is only a strawman, and that other DAMA techniques may well prove equal or superior to Round Robin (possibly conflict free multiple access or some modified form of CPODA designed for data service only and which provides a stable request channel). Further analysis of these broadcast schemes is required before a firm recommendation can be made.

The chosen earth station manning level is considered the minimum for attended operation. Advances in earth station technology and diagnostic self test no longer dictate the high manning levels of the 60's and early 70's. A four-man-year per year level will provide for the twenty-four hour operation, preventative maintenance and emergency repair required in an application as critical as the IAS.

5. TERRESTRIAL TRANSMISSION

a. Description. The terrestrial transmission subsystem for the strawman 1990 IAS is designed to complement the satellite system by providing subscriber access to the 60 PSN/earth station locations. No terrestrial backbone links are used, as internode connectivity will be via satellite. Access lines are costed at MPL rates, since TELPAK rates will not be available. Approximately 50 percent of IAS subscribers will require line speeds greater than 1800 bps. Total terrestrial system cost is therefore estimated to be approximately 57 million dollars annually (1990 dollars) using data from Figure 7 and the ratios in Table XIX.

b. Discussion. By 1990, it is projected that competition will have eliminated TELPAK rates from the overall tariff structure. This matter is still in litigation and the arguments are far from clear. The ultimate outcome will be determined by political as well as technical and economic factors, so no firm projection can be made at this time. Nevertheless, this strawman scenario assumes no TELPAK tariff in an effort to illustrate the potential impact of such a result. If TELPAK is not eliminated, 1990 annual terrestrial costs are expected to be approximately 47 million dollars annually.

The figure of 50 percent for the proportion of subscribers requiring access lines greater than 1800 bps is an estimate based on the 60 percent figure of the AUTODIN II data base modified by the inclusion of AUTODIN I subscribers in the IAS. Many subscribers can be expected to opt for higher speed service due to advances in terminal technology and improved switching services provided by the IAS. If the proportion of high speed subscribers varies from this estimate, annual costs will vary as shown in Figure 7. (These figures should be multiplied by 0.50 to account for reduced access line requirements resulting from 60 nodes vice 15. See Table XIX.)

An additional point should be made regarding the above estimates. Access lines were costed at commercial MPL tariff rates adjusted for inflation. These represent domestic rates, even though they are applied to access line costs worldwide. Tariffs for digital lines overseas are currently much greater than they are in CONUS. This disparity is expected to narrow by 1990, and in the absence of more definitive data on overseas line rates, projected domestic figures will be considered representative.

6. TOTAL STRAWMAN SYSTEM COST

a. General. Based on the strawman system configuration described above, overall system cost can be expected to run approximately 100 million dollars per year in 1990. Table XXI breaks this figure down, showing the contribution of the individaul system elements to the total.

b. Discussion. From Table XXI, it can be seen that the biggest single contributor to overall system costs is the terrestrial access subsystem, accounting for over two-thirds of the annual costs. To reduce access line costs would mean increasing the number of earth stations. As pointed out earlier in this chapter, the expense of added switching assets, while not addressed in this study, will quite likely result in diminishing returns beyond four to six switches per "original PSN area." This cost tradeoff should be investgated in more detail as part of the overall IAS architecture determination process.

Manpower costs are the next biggest cost item, totaling almost 22 percent, even for what is felt to be a minimum loading. Unattended terminals could result in substantial cost savings, but the expense required to insure earth station reliability (perhaps fully redundant systems and hot standby operation) might make such an approach unfeasible.

The cost of the space segment is felt to be relatively insensitive to other system parameters and is a rather small portion of overall system cost.

Earth segment costs hinge on the availability of a dedicated transponder in each DSCS III satellite for IAS TDMA use. If a full transponder is not available and sharing is required, the entire system equation is altered, forcing substantial additional expense on the earth segment, while reducing space segment costs only slightly.

TABLE XXI. SYSTEM COST ESTIMATE, 1990 IAS STRAWMAN IMPLEMENTATION

	Total Cost	Annual Cost
Space Segment:		
3 DSCS III transponders, launched via space shuttle	$ 16.M	$ 2.5M
Earth Segment:		
60 earth stations, G/T = 30.5 dB/°K TDMA, Round Robin Reservation	53.6M	8.3M
Manpower - 4 MY/YR per earth station, $90.4K/Man-Yr	--	21.6M
Terrestrial Access:		
Access lines at MPL rates 50% > 1800 BPS	--	67.0M
Total Annual Cost (1990 dollars)		$99.4M

VIII. CONCLUSIONS AND RECOMMENDATIONS

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1. CONCLUSIONS

Based on the assumptions adopted throughout this study, broadcast satellite transmission has significant cost reduction potential for the IAS; however, a suitable broadcast demand assignment technique has not yet been implemented. In addition to the cost savings opportunities, operational benefits can be realized inlcuding increased reliability, maintainability and error performance. A major concern in military satellite communications is its susceptibility to jamming or other hostile threat. With increased technology advancement, including intersatellite links, onboard signal processing and adaptive null steering antenna techniques, greater satellite system survivability will result. Specific findings are detailed below concerning the relative cost effectiveness of satellite configurations and the implications of various demand assignment methods.

a. Satellite System Cost Savings. Any future satellite application will be highly sensitive to man-loading requirements of earth stations as well as the number of earth stations deployed in a particular configuration. At current manning levels, satellite communication is not feasible in any case, but with minimal manning (4 MY/Y) net savings can be realized over a terrestrial system for any realistic projected number of terminals. The maximum savings at this man-loading occurs in the 30-90 earth station range, as depicted in Figures 8 and 9. The magnitude of savings for this configuration over an equivalent all terrestrial transmission system is expected to range from 11 million dollars to 55 million dollars annually, depending on terrestrial tariff structures.

b. Demand Assignment Techniques. Certain broadcast/demand assigned multiple access techniques have been examined during the study. Two methods show promise for potential application to the IAS with minimal increase in total cost over pre-assigned TDMA. These are conflict-free multiple access and Round Robin Reservation schemes. Both have been simulated for interactive computer communications use, which although similar to IAS requirements, also differs in many respects, particularly in overall subscriber and traffic characteristics. CPODA also has potential if it can be tailored for data use and the request channel can be made stable.

2. RECOMMENDATIONS

Results of this study indicate significant savings are realizable through utilization of demand assigned broadcast satellite

technology. This preliminary assessment is based on the engineering assumptions made necessary due to the current lack of a defined 1990 IAS configuration.

a. Terrestrial Transmission Facilities. The worldwide terrestrial segment of the DCS must be more accurately defined before cost tradeoffs can be made with a greater degree of accuracy. Since the costs for terrestrial transmission are topology and tariff dependent, system configuration alternatives should be defined prior to making any futher tradeoffs.

b. Space Segment Assets. It is apparent that a TDMA satellite broadcast system for IAS is feasible only if an entire transponder is available. The implications of sharing a DSCS III or INTELSAT V transponder with other users include the need for very large (and costly) receive subsystems at earth terminals, which can quickly overcome terrestrial transmission savings. The assumption that the IAS will have high enough priority to justify the use of dedicated transponder should be validated; and, if not feasible for DSCS III, the provision of a separate, narrow (5 MHz) transponder on the next generation spacecraft should be considered.

c. Broadcast, Demand Assignment Techniques. Several experiments are being conducted to develop broadcast techniques over satellites. Mostly based on ALOHA packet radio, these experiments will specifically analyze high speed data transfer via satellite. One research program is being conducted by Linkabit Corporation, and their findings will be released the latter part of 1978. These programs should be closely monitored and their results and findings included in the overall evaluation of satellite broadcast applicability and cost of implementation.

3. SUMMARY

The results of this preliminary analysis indicate that a broadcast DAMA satellite approach is feasible for the 1990 IAS. These results should be continuously updated and refined throughout the stages of architecture definition, evaluation and selection. This iterative process will better define the cost savings and operational improvements realizable for the 1990 system configuration. Future efforts should specifically include:

- A further definition of users and supporting and competing architectures

- A computer simulation model to evaluate various IAS satellite configurations

- A computer simulation model to evaluate potential DAMA techniques for IAS traffic only

- An improved definition of earth station man-loading requirements consistent with the projected state-of-the-art for earth stations

- Further assessment of survivability requirements and related developments in DCA Satellite Communication Programs.

A final concern is the basic issue of dedicated military satellite systems and the impact of commercial satellite offerings. Congress recently mandated that DOD lease satellite service from commercial carriers and rejected funding for follow-on satellites to the FLTSATCOM program. This could impact IAS satellite programs or the potentital system designs. Currently, there are no plans for any satellite carrier to develop broadcast satellite systems based on a TDMA/demand assigned technique. The potential savings and improved communications available from satellite applications, therefore, demands periodic assessment as the architecture evolves.

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